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LEVEL II

AN ANALYSIS OF AN R&D PROGRAM
SELECTION PROCESS AT THE
AERONAUTICAL SYSTEMS
DIVISION

Duncan B. McIntosh, Captain, USAF

LSSR 84-80

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During the development of the Aeronautical Systems Division's input to the 1982-1986 Program Objective Memorandum (POM), the Defense Wide Management and Support (DWMS) Mission Area Review panel had to evaluate seventeen R&D programs containing approximately seventy decision packages and produce a priority listing of those decision packages. This is the lowest level of zero-base budgeting in the federal government. It is very difficult for the DWMS panel to evaluate and rank DWMS decision packages because this mission area contains support programs which cannot be tied directly to Air Force goals. This thesis develops a scoring model which will aid the DWMS panel in determining the benefits of each decision package to the Air Force. Once the benefits have been determined, they are used as the objective function coefficients in a 0-1 integer programming selection model which explicitly includes project interdependencies in either the benefit function or the resource constraints. Using the selection model, a procedure is presented which develops the decision package ranking required for the POM. Finally, a schedule of events is developed which will allow the DWMS panel to more effectively evaluate and rank DWMS decision packages for the 1983-1987 POM.

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AN ANALYSIS OF AN R&D PROGRAM SELECTION PROCESS AT THE AERONAUTICAL SYSTEMS DIVISION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

Duncan B. McIntosh
Captain, USAF

September 1980

This thesis, written by

Captain Duncan B. McIntosh

and approved in an oral examination, has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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Chapter 1

INTRODUCTION

The selection and funding of an R&D portfolio is a difficult and important decision process for any organization which is involved in research and development tasks. The future business base and the relationship of the organization to its environment are determined by the type and level of effort of current R&D projects. If an organization does not adequately fund current research efforts having the highest possible benefits, it could find itself lagging its competitors in the future, losing its market share or present status, and possibly not surviving in its present form. For a private company, unemployment and economic depression for the local area could be the result, but for the U.S. military, the results could be detrimental to the country's survival.

The U.S. Air Force (AF), as well as all the other services, has to be continually assessing the perceived threat to the nation and determining how to meet that threat in the most effective and efficient manner possible. AF managers have to be able to evaluate all current and proposed R&D projects with respect to the current AF goals and objectives in order to effectively and efficiently allocate resources to those projects which provide the greatest benefit to the security of the United States. Since all resources are limited, the AF has to compete with all other federal agencies for funds. The ultimate challenge for AF managers is to provide the nation with the weapon systems which yield the most security per dollar spent.

This study is concerned with an investigation into the program evaluation and ranking process used by the Defense Wide Management and Support (DWMS) Mission Area Review panel at the Aeronautical Systems Division (ASD) for the 1982-1986 Program Objectives Memorandum (POM). The purpose of this ranking process is to develop a list of programs, within the DWMS mission area, based upon their contributions to AF objectives. This list represents the panel members' preferred order for funding programs within the DWMS mission area. Evaluating DWMS programs with respect to AF objectives is a difficult undertaking because DWMS programs are support programs and contribute to the objectives of several or all of the other mission areas. The overall intent of this investigation is to develop recommendations and conclusions which can aid the DWMS review panel during the next POM exercise.

Aeronautical Systems Division

The Aeronautical Systems Division is one of the four product divisions of the Air Force Systems Command and is tasked with the mission of planning and managing the acquisition of all aeronautical weapon systems, subsystems, and equipment for the United States Air Force (ASD/AV, 1980:3). In performing its mission, ASD has to supervise many types of programs at different stages of development. The majority of programs under ASD control are either advanced development, engineering development, or procurement programs with very little of the actual detailed design work on a system performed at ASD. The engineers and managers at ASD supervise contractor's performance; design and write specifications for system design and operation; supervise cost and schedule performance; and manage conflicts between costs, schedule, and product performance.

All of ASD's programs can be grouped into the following seven mission areas: strategic offense, strategic defense, air-to-surface attack, counterair, reconnaissance, mobility, and defense wide management and support (Weber, 1980a). AFSC Regulation 80-2 states that ASD will, for each mission area:

> . . . evaluate each R&D program assigned to the Product Division and provide to HQ AFSC/XR (Developmental Planning) each year, before the AFSC POM submission, an overall integrated Product Division R&D program, including relative rank of each program by mission area as supported by analysis and rationale [AFSCR 80-2, 1978:2].

This Product Division R&D program evaluation and ranking process is the lowest level of zero-based budgeting within the Department of Defense.

Three different levels of management at ASD are involved in the decision package ranking process. To initially rank the decision packages, Mission Area Review panels are established for each one of the seven mission areas. These panels evaluate and rank all decision packages within their assigned mission area. Next, the Program Review Group reviews and makes appropriate changes to the proposed rankings within each mission area. Finally, these proposed rankings are briefed to the Decision Review Group which is chaired by the ASD Commander. Upon approval by the Commander, the rankings are forwarded to AF Systems Command as ASD's input to the POM process (ASD/AV, 1980:15).

AF Systems Command incorporates the mission area program rankings from ASD with the mission area program rankings from all other agencies within AFSC and determines one ranking for each mission area which is AFSC's input to the AF POM. The Air Staff has to incorporate the AFSC's programs with all other Air Force programs in order to develop the AF POM.

Defense Wide Management and Support

The purpose of the Defense Wide Management and Support mission area is to provide for support programs that are common to one or more of the combat mission areas and to improve the quality of that support while trying to reduce operations and maintenance costs (Weber, 1980a). This mission area is composed of many different types of programs which support the combat mission areas and provide indirect contributions to the elimination of deficiencies in the AF. Not only can one DWMS program contribute to the accomplishment of more than one mission area's objectives but also that program can contribute various percentages in each applicable mission area. The process of evaluating the contributions of DWMS programs to AF needs and making trade-off decisions between programs in order to rank them for the POM is a very complex decision process.

Statement of Problem

The DWMS panel members interviewed indicated that they need a more efficient method developed to evaluate and rank all the programs within the DWMS mission area for the POM. Several issues which are inherent to the problem of having an inefficient evaluation and ranking process are included in the following questions which will be addressed in this research. Does the information about each program provided to the panel represent the most current and accurate description of that program? What documents are available to aid the panel members in evaluating the contribution of each program to the needs of the AF? What is the best method of judging the benefits from each program? Knowing the benefits, what is the best method of allocating budget resources to the optimal portfolio of projects in order to maximize the benefits to the Air Force?

Statement of Objectives

The objective of this thesis is to evaluate the process that the DWMS panel used in developing the 1982-1986 POM and to develop improvements to the process in the following four areas:

1) collecting information from the program managers about their programs;

2) using AF documentation to tie DWMS programs to the long-term goals of the AF;

3) evaluating and measuring the benefits to the AF from the programs; and

4) selecting a portfolio of projects within given budgetary constraints.

Methodology

During the 1982-1986 POM exercise, the DWMS Mission Area Review panel had to evaluate seventeen programs containing about seventy decision packages and rank the decision packages according to their benefits to AF objectives. The panel members used a scoring model, which contained four criteria, to evaluate each individual decision package and then obtained a total decision package score by summing the individual scores. Next, the decision packages were ranked according to their total scores. Adjustments, based upon the panel members' expert opinions, were made to the initial ranking if the panel felt that this ranking did not accurately reflect the true relationship between decision packages. Finally, the cumulative cost for adding decision packages according to the ranking structure was determined and compared to the budget figure. All packages whose cumulative cost was less than or equal to the budget figure were included in the recommended project portfolio while projects whose cumulative cost was greater than the budget figure were excluded. Chapter 4 contains a detailed analysis of the ranking process used by the DWMS panel.

The purpose of this research is to evaluate the effectiveness of the process the DWMS panel used during the POM exercise and to recommend improvements for the 1983-1987 POM exercise. Initial discussions with the DWMS panel chairman and initial reviews of the POM guidance documentation indicated that four major areas needed to be investigated. The first area concerns the concept of zero-base budgeting in the federal government since the ranking process performed by each Mission Area Review panel is the lowest level of ZBB at ASD. The second area of investigation is concerned with the availability of AF documentation which relates AF programs to AF objectives by mission area. The panel relied only on the information contained in the decision packages and the program managers' briefings. The next two areas deal not with the collection of project information but how to use that information to evaluate and select an R&D project portfolio. Once the most relevant information is provided to the panel, what is the best method to combine that information with the expert opinions of the panel members in order to realistically determine the expected benefits of a decision package to the AF? Finally, given the expected benefits for each decision package, what is the best method (scoring models, economic models, mathematical programming models, or other approaches) to select an R&D project portfolio which maximizes the total possible expected benefits to the AF?

In order to evaluate the decision package ranking process used by the DWMS panel and how it relates to ZBB the following criterion was used: how well did the DWMS panel apply the theory of ZBB to the R&D project portfolio problem? In order to evaluate the criterion three sources of information were used. First, a literature search was conducted into the theory of ZBB which provided background material on how a ZBB process should be conducted within an organization. Next, a questionnaire was developed which was aimed at evaluating the DWMS panel members' knowledge of ZBB and obtaining an understanding of the actual process the panel used to rank decision packages--ZBB as actually applied in an organization. The actual process as stated by the panel members was compared to the theoretical ZBB methodology as expressed in the literature in order to recommend improvements for the 1983-1987 POM. Finally, the AFSC POM guidance was reviewed in order to determine if the decision packages contained the type of information that theoretically should be contained in a decision package.

In order to investigate the availability of AF planning documentation, a literature search of the DOD's Planning, Programming, and Budgeting System was conducted in order to determine what documents were available for use by the DWMS panel. The most important consideration was whether these documents contained information that could aid in relating DWMS programs to AF objectives and needs. A secondary consideration was whether these documents would be readily available for the panel's use during the POM process. Finally, when the panel members were interviewed, they were asked what documents they would like to have had available, and the results were compared to the PPBS documents theoretically available.

A major problem encountered by the DWMS panel was, what is the best method for evaluating and ranking decision packages? Only a broad outline was offered by the POM guidance with the specific details left up to the individual Mission Area Review panels. In order to collect information from which recommended improvements could be made, three sources were used. First, the panel chairmen from six of the seven Mission Area Review panels were interviewed in order to discuss the methodology they used to evaluate and rank decision packages. Next, the DWMS panel members were interviewed in order to obtain their personal interpretation of the evaluation criteria used by the DWMS and possible improvements for the future. These interviews provided the practical aspects of project evaluation which were compared to, the third source of data, suggested approaches from the literature. These results were used as a basis for modifying and improving the scoring model used by the DWMS panel for the 1982-1986 POM in order to increase the consistency in project evaluations. Validity of the model was checked by its similarity with other approaches in the literature and by the DWMS panel chairman reviewing and commenting on the model.

Finally, once the project benefits have been determined, a model has to be developed which maximizes the expected benefits from an R&D project portfolio given certain resource constraints. The model must allow for project interdependencies rather than treating the set of projects as independent. The scoring model that the DWMS panel used during the 1982-1986 POM did not consider project interdependencies although the panel members did make tradeoff decisions between projects after the scoring model produced the initial ranking. Based on a literature search into R&D project selection techniques, a specific model was chosen and its use demonstrated. Advantages and disadvantages of the specific model chosen are discussed and its use demonstrated by several examples. It is important to note that the actual usefulness of the model to the DWMS panel can only be judged when it is applied during the development of the 1983-1987 ASD POM.

Format of Thesis

Chapter 2 discusses zero-based budgeting and the Planning, Programming and Budgeting System in the federal government. The literature search into ZBB provides the background material for the investigation into the problems that have occurred at ASD in collecting program information to effectively rank those programs for the ASD POM. The PPBS background material provides information that is useful in determining what planning documents are available to aid the DWMS Mission Area Review panel in evaluating programs with respect to AF goals and objectives.

Chapter 3 discusses R&D project evaluation techniques and R&D project selection models. A detailed literature search into project evaluation techniques provides the background information needed to develop an efficient evaluation methodology which the DWMS panel can use to judge the benefits of the DWMS programs to the AF. Different project selection techniques are investigated in order to determine the appropriate technique which will pick the optimal project portfolio.

Chapter 4 discusses the DWMS mission area in detail and presents the panel members' responses to the interviews. Their responses are combined with the ZBB philosophy in order to recommend changes that would aid in improving the information provided by the program managers about their programs.

Chapter 5 develops a methodology which the DWMS panel could use in the future to aid in evaluating DWMS programs. Based upon the literature search and ideas obtained during the interviews, the evaluation criteria are improved. Once the benefits for each project are determined, a mathematical programming model is proposed which will optimize the portfolio of projects rather than treating each project as a mutually exclusive entity.

The last chapter, Chapter 6, presents the major conclusions of this study and recommendations to the DWMS panel that can be used to improve the POM ranking process for the 83-84 POM.

Chapter 2

THE RESOURCE ALLOCATION PROCESS IN THE DEPARTMENT OF DEFENSE

The purpose of this chapter is to discuss the theoretical requirements of a ZBB system and to discuss the PPBS in the Department of Defense. DOD's management, in the early 1960's, established a planning, programming, and budgeting system in order to organize the budget process and to tie needs to programs and programs to the budget. When Jimmy Carter became President in 1977, he directed the federal government to establish a zero-base budgeting system for the federal budget process. This action has been completed, and the DWMS program ranking process for the AF POM is the lowest level of ZBB in DOD. The theoretical philosophy of ZBB provides a base line to which the actual DWMS ranking process can be compared in order to develop improvements. The discussion of the PPBS in DOD provides information pertaining to the documents that are available to aid the DWMS panel in the program evaluation process.

Zero-Base Budgeting

Although the concept of zero-base budgeting (ZBB) can be traced back to 1924, it was not until Peter Phyer of Texas Instruments published the results and experiences of his firm in implementing ZBB in 1969 that the process became widely used. In its general form, ZBB is an incremental budgeting system that emphasizes increments as well as decrements to the budget (McLaughlin et al., 1980:1). The existence of every program, new and old, has to be justified and reviewed each year during the budget process in order to select those programs which provide the highest possible benefit to the company for the money expended. If a new program generates a higher return than an old program or if two old programs switch positions with respect to their benefit rankings, then ZBB allows the manager to make realistic tradeoff decisions between programs when some require and justify higher expenditures and others require a decreasing expenditure (Burroughs, 1977:11).

When Jimmy Carter was governor of Georgia, he directed the state to convert to a zero-base budgeting system so that every program could be reviewed and justified each year. Each state agency would be required to identify each function it performs and the personnel and cost to the taxpayers for performing that function (Suver and Brown, 1977:79). It was estimated that for the state of Georgia's 1972-1973 fiscal year approximately 11,000 decision packages had to be identified, evaluated, and ranked before Governor Carter reviewed the final group of packages. A study conducted after the implementation of ZBB in the state of Georgia indicated that the process led to an improvement in the quality of management information and to greater involvement with the budget, but that it had not significantly changed the resources allocated to programs in the state (Herzlinger, 1979:4).

Candidate Jimmy Carter promoted ZBB as a means of cutting federal expenditures during his 1976 presidential campaign. Harvey states that the image of ZBB is one of significant cost reduction but unless an organization has already decided in advance to cut its level of spending, it is unlikely that ZBB will produce an automatic overall cost reduction. The appropriate place for ZBB is in the private sector where bottom-line performance standards such as market share, profit, and investment return enable managers to effectively prioritize their activities. The value of ZBB to the government is diminished by the relative lack of useful bottom-line measures of performance (Harvey, 1978:33-34). Anthony calls zero-base budgeting a fraud (Hyde, 1978:321), but Herzlinger states that like most other management techniques, ZBB is neither a panacea nor a fraud.

> It is, rather, a process which can yield substantial benefits if properly implemented, but which can be neutral or even pernicious in its effect if sloppily or thoughtlessly executed [Herzlinger, 1979:3].

Herzlinger questions whether ZBB is appropriate for the entire budget of a large political system. Cheek claims that the main benefit is that ZBB helps to improve innovation in an organization.

> In forcing yourself to go to zero base, regularly and systematically, you force yourself to come up with creative,

innovative, alternative ways of delivering the same service at less cost, or greater service at the same cost [Cheek, 1978:23].

Concepts

The basic concept of ZBB is that at regular intervals all program managers have to evaluate the effectiveness of their programs in terms of corporate goals and submit to their superiors a detailed evaluation of their programs at various funding levels in order to justify their right to exist. The manager must be able to justify each activity's projected level of expenditures, and no level is taken for granted (Suver and Brown, 1977:81). The superior ranks all the programs under his control and sends this priority listing to the next level of management. Each hierarchical level within the organization reviews and priority ranks all programs under its control. By the time top management reviews the programs, they will have all the inputs by lower management on the relative importance of the programs and by combining their judgement with the views of lower management, arrive at the resource allocation for the firm.

McCandless discusses six steps in designing and implementing a zero-base budgeting system. First, top management has to provide all managers with the strategic plan of the organization and the specific planning and policy assumptions used to derive that plan. Without specific guidelines, it would be impossible to ensure that all managers are using the same assumptions during the ZBB process (McCandless, 1978:46). Top management will have developed strategic assumptions and goals whether stated implicitly or explicitly. If these assumptions can be communicated explicitly to their subordinates, then lower management will have an idea where the organization is planning to go in the long term and how it plans to get there. Program managers will be able to formulate their decision packages to focus on and support the long range plan of the organization (Cheek, 1978:26).

The second step is the establishment of the organization's decision units, which are the smallest discrete units of activity in the organization that are being considered for resource allocation. For example, in DOD the decision units are the individual program elements. The size of the organization should be considered when designing the decision units. In a very large organization, too fine of a division will result in a very large number of packages to evaluate at superordinate levels because most decision units will submit at least three decision packages (McCandless, 1978:46). The state of Georgia had over 11,000 packages to evaluate, and it would be impossible for one person to evaluate all the programs in the federal government. If the decision units are too large for analytical or informational purposes, while easing the mechanics of budgeting, managers will have an extremely difficult job priority ranking the programs. Herzlinger states that the decision unit selection problem can be minimized by assigning the decision unit selection task to the managers and budget people who will be using the data (Herzlinger, 1979:11).

Next, each program manager analyzes his programs and writes the decision packages which justify various levels of effort and resource requirements. Generally, at least three different decision packages are written for each program by the program manager. Each package is a description of the program's objectives and an evaluation of alternative means of achieving those objectives (Shapiro, 1979:40). The first package is the basic or minimum package, which includes those projects that are required by law or that have previous obligations as well as basic functions required for the program to exist. It is the minimum level below which the program ceases to exist (Suver and Brown, 1977:78). Decision package two represents the current funding level while package three is an increment above the current level and represents an increased level of effort (Burroughs, 1977:11). McCandless states that the decision packages are usually written on an incremental basis where package two is expressed as an increment above package one and accepting package two implies the acceptance of package one (McCandless, 1978:46).

Burroughs states that each decision package should contain the following elements: the purpose, the consequences of not performing that activity, measures of performance, alternatives, and cost/benefit analysis (Burroughs, 1977:8). The purpose of the decision package should be related to the strategic goals of the organization. Without this relationship explicitly stated, it is difficult to evaluate the contribution of that decision package to the strategic plan of the organization. If the contribution of a particular decision package to the organization was either not clearly stated or misstated, it would be possible to overlook a highly favorable package. A basic requirement in order for any organization to efficiently achieve its long range plan is for that organization to select those programs today which have the highest contributions to that plan. Cheek claims that ". . . ZBB is nothing more than a logical, systematic, disciplined, common sense framework to harness and channel an organization's resources towards preagreed goals and objectives [Cheek, 1978:25]."

Included next in the decision packages should be a description of the consequences of not performing this activity. Cheek claims that one of the major benefits of ZBB is that it is a communications tool that improves decision making and fosters innovation throughout the organization (Cheek, 1978:24). Burroughs states that one of the best reasons for developing decision packages is that "in order to do so effectively, managers must evaluate their organizational structure and the interrelationships among activities and organizational units

[Burroughs, 1977:8]." If the decision packages are to be used as a valuable communications device between the program managers and higher management, the decision packages have to contain realistic information on how the ultimate goals of the organization will be effected if this activity is not performed.

Third, each decision package should include performance measures for evaluating the effectiveness and efficiency of the proposal. Performance measures are needed that clearly measure the accomplishment of the stated objectives (effectiveness) and assess these accomplishments in terms of the resources used (efficiency). Letzkus states that explicit articulation of objectives is required in order to evaluate the effectiveness and efficiency of a program. Many authors feel that it is impossible to evaluate the effectiveness of government programs in the absence of a clear unambiguous statement of objectives which identifies not only performance standards but also expectations over a specified period of time. The output from many government programs is often difficult to identify because it is in the form of intangible services which results in a frequent temptation to measure resources applied to the attainment of the objectives rather than to measure the actual attainment of those objectives (Letzkus, 1978:35-36). "Although it is better to try to quantify the right performance measures, it is easier to select those that lend themselves to quantification [McCandless, 1978:49]."

People tend to measure the easily measurable rather than what should be measured. Nonetheless, a basic requirement of any program evaluation is a clear, specific statement of objectives (Letzkus, 1978:35).

The fourth element in the decision package should be a discussion of the alternatives evaluated by the program manager (Burroughs, 1977:8). Cheek claims that ZBB increases innovation in an organization by forcing program managers to think creatively in coming up with alternative ways of operating (Cheek, 1978:25). The program manager should evaluate different ways of and different levels of effort for performing the same function (Burroughs, 1977:8). Included in the alternative means of achieving the stated objectives should be the reasons why certain alternatives were rejected (McCandless, 1978:45). One of the most significant features of ZBB is that it communicates to upper management what the people responsible for the programs consider as areas of importance and where the program managers would reallocate resources given either an increment or decrement in their budget.

Finally, the last element in the decision package is to provide a description of the costs and expected benefits (Burroughs, 1977:8). Costs, although difficult to estimate especially for uncertain R&D programs, do not present as difficult a problem as the estimation of future benefits especially for federal programs when the output is in the form of intangible services and cannot be well defined. How does one measure this output or expected benefits? Letzkus discusses the problems involved in choosing the appropriate indicator of output, whether single, multiple, or composite measures are appropriate, in order to determine the benefits of a particular program (Letzkus, 1978:35).

The fourth step of the ZBB process is that the decision packages are ranked according to their contribution to the goals of the organization (McCandless, 1978:46). The difference between ZBB and other budgeting approaches is that with ZBB every manager in the company's hierarchy reviews and prioritizes all programs under his control. Burroughs states that "the process identifies, to all levels of management, the costs, benefits, and suggested operational levels associated to reach their objectives [Burroughs, 1977:8]." Shapiro suggests that the ranking process be conducted by a group which evaluates incremental decision packages against one another (Shapiro, 1979:42). Suver and Brown suggest that the group members should be the program managers whose packages are being ranked and their supervisor should be the panel chairman (Suver and Brown, 1977:78). McLaughlin et al. discusses the use of and problems associated with the use of expert panels, nominal group techniques, and scoring models to rank programs (McLaughlin et al., 1980:4). The U.S. Office of Management and Budget Bulletin No. 77-9 states:

> The ranking shows the relative priority that discrete increments of service or other outputs have in relation to other increments of service or other outputs. The process is explicitly designed to allow higher level managers the opportunity to bring their broader perspectives to bear on program activities by allowing them to rank the decision packages and make program trade-offs [Hyde, 1978:311].

McCandless states that the fifth step is the preparation of the final budget in a contingency form (McCandless, 1978:46). Top management reviews their final priority ranking of programs and compares the cumulative cost of those programs to the total budget figure. All decision packages for which the cumulative total is less than the budgeted amount are included in the portfolio of programs while those whose cumulative total are greater than the budgeted amount are excluded. All programs which are included in the final portfolio constitute the operating budget for the organization (Shapiro, 1979:40). The purpose of the ZBB priority ranking is to indicate which decision packages should be added first if the budget is increased and which should be the first to go if the budget is decreased (McCandless, 1978:46). The decision packages deleted or added will be based upon the priorities established by those managers responsible for the execution of those decision packages (Burroughs, 1977:8).

The final step is that the managers are given feedback on the final rankings. McCandless states that ". . . the reasons for any changes in rankings made by higher management levels are passed down to the lower-level managers. This should help build up trust in senior management [McCandless, 1978:46]." Since one of the purposes of the ZBB process is to allow higher management to make realistic tradeoffs between programs and to redirect funds based upon the recommendations and evaluations of lower managers, feedback should be provided so that lower managers don't feel "done to" if their program is cancelled or don't feel like the process is a waste of time (Burroughs, 1977:11). If feedback is provided, organizational trust in top management will be increased because subordinates will trust their superior's ability and fairness and will submit reliable, complete, and unbias information in the future (McCandless, 1978:47).

Benefits

The major benefits of the zero-base budgeting process are that the process fills a communications void in the organization, allows top management to make realistic tradeoff decisions between programs, allows managers to obtain a better understanding of how their organization is structured and operates, and allows lower level managers to feel an ownership for the final budget because of their contributions to the process. Harvey claims that ZBB is a useful general management process because it fills a communications void in the organization (Harvey, 1978:33). One of the most significant characteristics of ZBB is that information flows from the bottom of the organization to the top (Burroughs, 1977:11). The ZBB process is an invaluable tool to communicating ideas and legitimate needs upwards to key decision makers (Cheek, 1978:24). Top management, by reviewing the information contained in the decision packages and the priority ranking established by lower managers, can make a more realistic redirection of funds from programs that have a decreasing resource requirement to programs which require a higher resource requirement. This reallocation of funds is in line with not only top management's priorities but also utilizes the priorities established by subordinates (Burroughs, 1977:8).

Another important aspect of ZBB is that in establishing and justifying each decision package, all managers are able to obtain a clearer picture about their organization. ". . . perhaps the most useful aspect of a zero-base system is a complete identification of the current and proposed programs and their costs [Suver and Brown, 1977:84]." It forces managers to explicitly link their resource requests with the benefits of their proposed activities and the objectives of the organization (Shapiro, 1979:40). In organizing and collecting the information required for the decision packages, the program manager can obtain a clearer picture of the interrelationships within his program, and the alternative means available to accomplish the program's objectives.

Decision packages therefore offer top management, boards of directors, or finance committees the opportunity

> to gain a better understanding of what's going on throughout the organization, what the objectives of the various subunits are, and how they are to be achieved [McCandless, 1978:46].

Harvey claims that an additional benefit is that all managers throughout the organization's hierarchy feel an "ownership" for the final budget because of their personal participation in the ranking process. For many managers, the implementation of a ZBB process is the first real opportunity that they have to significantly influence the direction of the organization.

> The value of budget ownership is seen when funds are finally allocated to the ranking list. Budget managers do not feel 'done to' but rather acknowledge the implementation of what was, in effect, their own budget and plan [Harvey, 1978:34].

Problems

Many authors have discussed the problems with zero-based budgeting. Anthony says that zero-based budgeting is a fraud. He claims that the name implies that the program manager starts each budget year at zero and has to justify every dollar requested when in fact a level of approximately 70 to 80 percent of the current spending level is established as the minimum package and given a cursory examination while attention is focused on the incremental packages. In a large organization, the large number of required decision packages would make the process unmanageable. A thorough analysis during the time available in the budget process would be impossible.

Another problem is that program rankings will be influenced by the expected amount of funds available or will be deliberately structured so that essential or politically popular packages are given a low ranking. If these lower ranked packages are reinstated, all of the higher ranked packages will, also, be included in the budget (Hyde, 1978:322).

Suver and Brown cited three disadvantages to the ZBB process from the experiences in the state of Georgia.

1) An increase in the time and effort required to prepare the budget.

2) When viewing the end result of the old budgeting system and ZBB, ZBB has not significantly affected the allocation of funds to programs.

3) The decision package ranking approach was ineffective in meeting changes in funding levels (when funds were increased or decreased, new decision packages were created instead of using the initial decision package rankings) (Suver and Brown, 1977:80). Further, McLaughlin et al. noted that additional problems could arise if the process is not done in good faith or if there is a great amount of post-acceptance manipulations (McLaughlin et al., 1980:2).

As discussed earlier, one of the major problems associated with the evaluation of any public program is how does one measure the outputs of such a program? Suver and Brown discuss the problem that output measurements in terms of achievement are either lacking, too subjective, or too argumentative (Suver and Brown, 1977:81). Letzkus addresses the performance measurement problem in terms of two factors:

1) differentiation between measures of work accomplished and the effectiveness of goal accomplishment, and

2) determination as to whether single, multiple, or composite measures will provide a true measure of performance (Letzkus, 1978:36).

Suver and Brown go on to say that problems can occur when management tries to compare outputs of non-related decision packages which is required in the ZBB process (Suver and Brown, 1977:81).

Another problem is that the implementation of the ZBB process represents major changes for an organization. McCandless discusses organizational change in terms of the model developed by Kurt Levin where one must unfreeze the old attitudes, change them, and refreeze the new attitudes in order to achieve the desired state. In order for the refreezing state to be effective, the organization's reward system has to reinforce the new behaviors (McCandless, 1978:47). Cheek claims that no matter how good a new idea is, large organizations resist change (Cheek, 1978:24). Suver and Brown state that many people feel that the replacement of an old system with a new system implies that the old system was inadequate. Many people in organizations resent and resist change (Suver and Brown, 1977:81).

The problems associated with the behavior implications of ZBB are a major factor in the acceptance of the process in an organization. ZBB requires every program to be reviewed once a year and its right to exist justified. This "life or death" situation can be perceived as a threat by the program managers and other employees working on the program (Letzkus, 1978:40). They will have a tendency to adjust the information provided in the decision packages in order to increase the likelihood of the acceptance of their program.

Finally, McLaughlin et al. discuss that perhaps, because of the amount of work involved, the ZBB process could better be addressed during slack periods of the budget cycle. The review of the budget may not be optimally performed during a period of heavy workload and deadlines (McLaughlin et al., 1980:2). Anthony suggests that perhaps the zero-base analysis could more effectively take place outside of the budget cycle (Hyde, 1978:322).

This section presented the concepts, benefits, and problems with zero-base budgeting which has now been fully integrated into the federal government's budgeting process. The next section discusses PPBS in the Department of Defense starting with the planning phase during which strategies and long range plans are developed, continuing through the programming phase where programs are developed to fulfill the long range plans, and finally, ending with the budgeting phase where the financial plan to fund the desired programs is developed. Especially interesting to the DWMS panel members would be those documents which update the FYDP, provide feedback about the previous POM, and relate programs to AF objectives.

Planning, Programming, and Budgeting

During the 1950s, the only control that the Office of the Secretary of Defense (OSD) exercised on the annual Air Force (AF) program was fiscal control. Essentially, there was no long range planning as the AF looked only at one year in the future when budgeting and there was very little integrated inter-service planning. Within the AF, planning in response to threat analysis was not connected to budgeting. A Planning, Programming, and Budgeting System (PPBS) was established within the Department of Defense (DOD) by Charles Hitch, the OSD Comptroller under Secretary of Defense (SecDef) McNamara, in order to correct these deficiencies in the DOD resource allocation process. The purpose of the PPBS is stated below:

> To bridge the gap between planning and budgeting, we developed a new programming system which relates missions to forces, forces to programs, and programs to budgets, and the whole is projected at least five years ahead [Fairfield, 1979:51].

Perhaps the greatest benefit from the PPBS is that it insures that budget dollars are related to programs (Fairfield, 1979:51). PPBS is very important to the AF in the allocation of resources to programs.

> The PPBS is the single instrumentality for allowing resource allocation decisions to be made and recorded. Consequently, any successful attempts to influence the allocation of resources will ultimately be reflected in this core planning system [AFP 172-4, 1979:13].

The PPBS cycle is composed of three separate phases; the planning phase, the programming phase, and the budgeting phase, all of which are based on the threat analysis by the Joint Chiefs of Staff (JCS). The process culminates in the President's budget being submitted to Congress in January. All three phases are a continuing process due to the overlap in budget cycles. One complete cycle from the issuance of the Joint Intelligence Estimate for Planning (JIEP) by the JCS to the passage of the budget by Congress is approximately a 33 month process. During this process, communication continually occurs between the President, the SecDef, the JCS, the Air Staff, and the user commands. The purpose is to determine the most efficient allocation of budget resources in order to meet current and projected threats. The PPBS can be summarized as follows: based on the anticipated threat, a strategy is developed; in support of that strategy, force requirements are developed; based on these requirements, programs are developed to provide, on an orderly basis, military resources over a period of time, with due consideration of the total cost to the nation; and lastly, funds must be budgeted in such a manner as to obtain the required forces and weapon systems within the resources that the nation provides (General Dynamics, 1979:4). It "fundamentally attempts to set the balance among the complimentary force and capability characteristics of structure, readiness, and modernization [AFP 172-4, 1979:19]."

Planning Phase

The purpose of the planning phase is to continually analyze the current and projected threats, determine how to best meet those threats, determine what the current and projected capabilities are in meeting those threats, calculate current and expected deficiencies, establish priorities, and to determine the best resource allocation in order to meet national objectives. Three somewhat independent planning systems provide input to and are tied together by the PPBS and are aimed at providing the unified and specified commanders with the forces they need. They are the Development Planning System, the Joint Operational Planning System, and the Joint Strategic Planning System (AFP 172-4, 1979:16). Figure 1 shows the relationship between the planning systems and the feedback from the operational planning system to the other systems.

Development Planning System

The development planning system is concerned with the

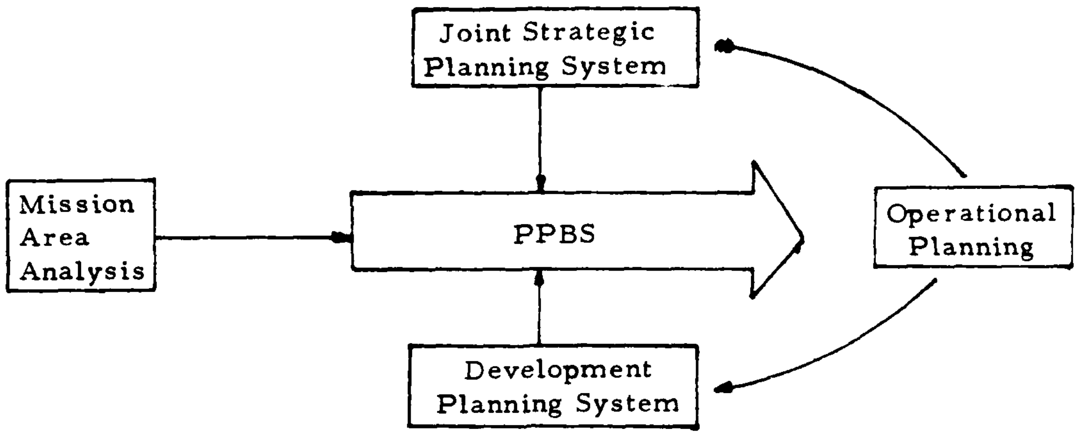

Figure 1: PPBS Planning System (AFP 172-4, 1979:16)

qualitative improvement of the military force structure and focuses on the modernization of capability. Developmental activity can be defined as Research, Development, Test and Evaluation, and Acquisition with the majority of the resources expended on major weapon systems acquisition. The developmental cycle is not tied directly to any given PPBS cycle but rather the monetary implications of various program alternatives are evaluated at key decision points or milestones, Figure 2. The funding profiles not only depend upon an economically sound program but also are adjusted yearly in response to the changing world environment and priorities among Air Force programs (AFP 172-4, 1979:19).

Conceptual Phase	Validation and Demonstration Phase	Full-Scale Engineering Development Phase	Production and Deployment Phase
Milestone 0	Milestone I	Milestone II	Milestone III

Figure 2: Major Systems Acquisition Cycle (AFP 172-4, 1979:19)

Joint Strategic Planning System

The Joint Chiefs of Staff (JCS) have the responsibility of formulating the strategic plans for the United States to meet the challenges of actual or potential enemy threats. The process through which the JCS performs this function is the Joint Strategic Planning System (JSPS) which eventually supplies planning and programming information for the PPBS (Fairfield, 1979:54). The PPBS is the process which ties the threat assessment of the JCS and other military planners to the budget the President presents to Congress in January. Figure 3 shows the relationship between the JSPS and the PPBS. In terms of the influence on the resource allocation process, of all the documents prepared by the JCS, the Joint Strategic Planning Document (JSPD) and the Joint Program Assessment Memorandum (JPAM) are the most influential in the PPBS process (AFP 172-4, 1979:17).

The JSPS starts with an analysis of the threat to the United States and its allies and the results are presented in the Joint Intelligence Estimate for Planning (JIEP). Information is provided by the services, the Defense Intelligence Agency (DIA), and from within the JCS. The JIEP assesses the threat over a short to mid-range time period and provides information that forms the basis for a JCS internal working document called the Joint Strategic Planning Document Supporting Analysis (JSPDSA) which is published in two parts (Fairfield, 1979:54).

Part 1 of the JSPDSA addresses the JCS's ideas on strategy and provides force planning guidance. This document provides other military planners with the JCS perception of the required military strategy in order to meet any perceived threat. The JSPDSA Part 1 is used by the Air Staff in order to conduct the USAF Objective Force exercise (Fairfield, 1979:54, 56).

Prior to the USAF Objective Force exercise, the component commanders submit to the Air Staff their "minimum risk forces." These forces constitute what the commanders think are required to defeat the threat as presented by the JCS, and these estimates are made without considering the constraints that will be applied later by the PPBS. The purpose of the Objective Force exercise is to take the minimum risk force structure and evaluate the possibility of

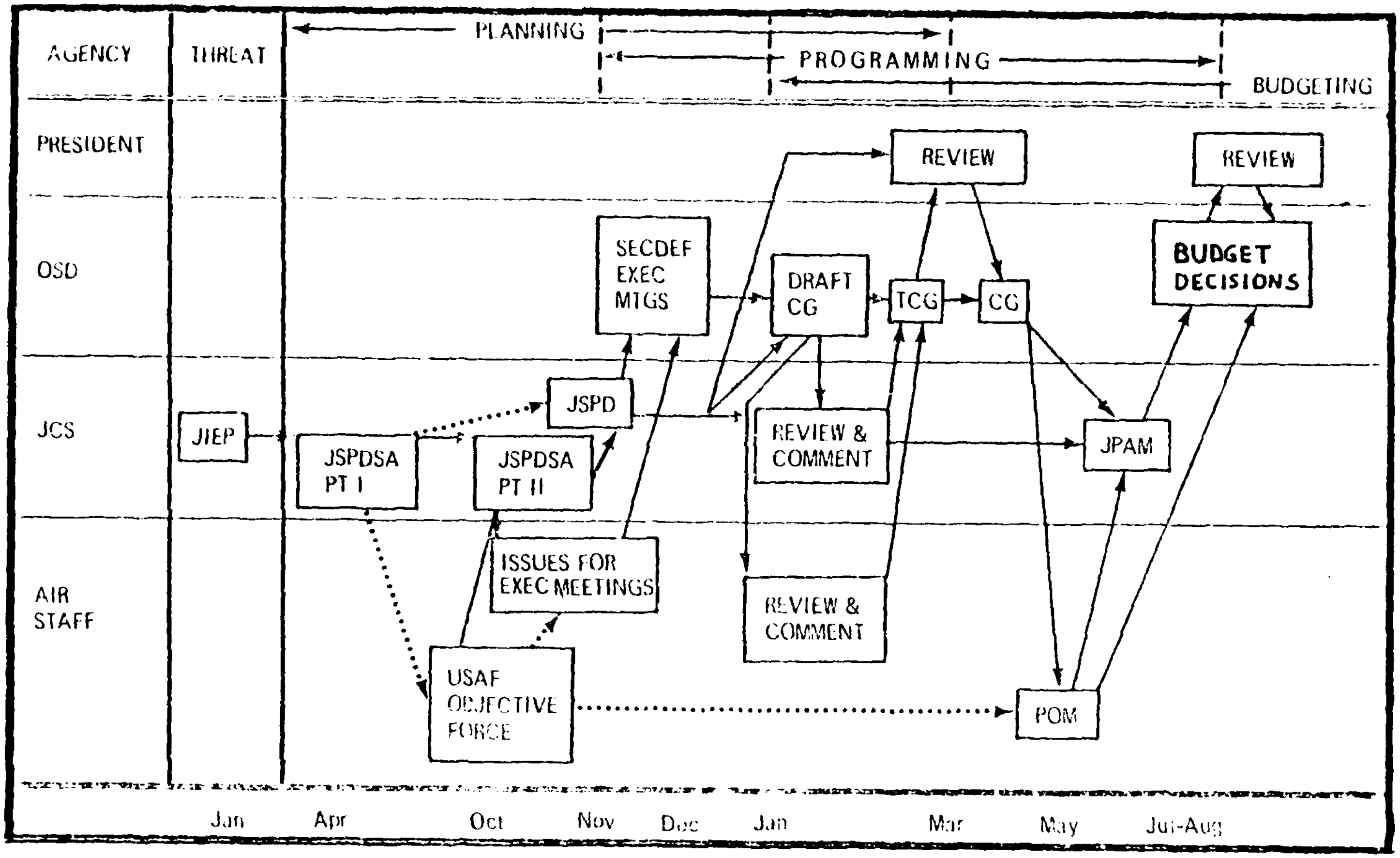

Figure 3: PPBS and JSPS

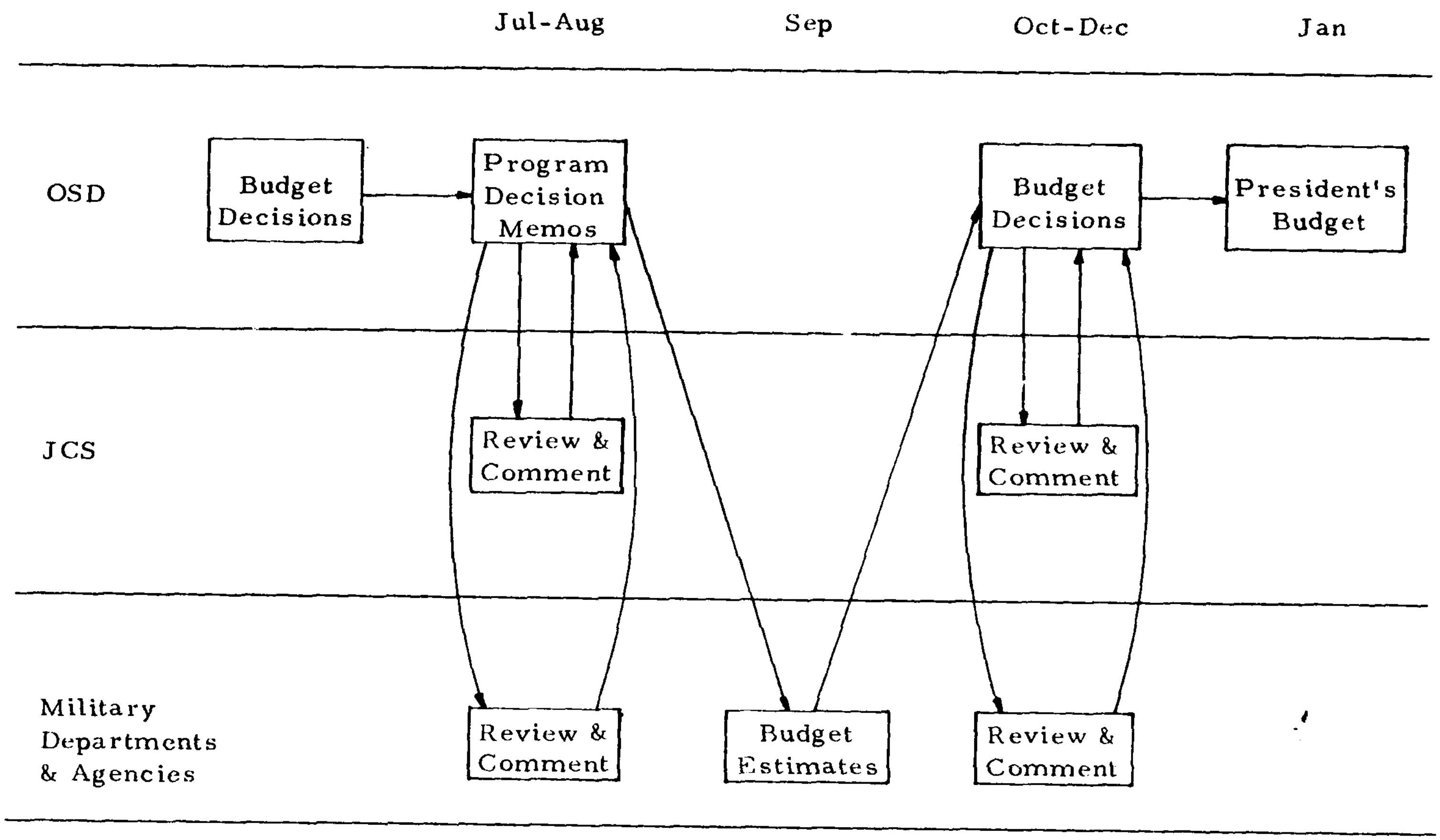

Figure 3 (cont.): PPBS and JSPS

obtaining these forces within the current and projected U.S. industrial capacity. The final result of the exercise is the "prudent risk force" which forms the basis for the JSPDSA Part 2 and the AF Program Objective Memoranda (POM) exercise (Fairfield, 1979:56).

The JCS, after reviewing the prudent risk force outlined in Objective Force, publishes the JSPDSA Part 2 which describes the force structure needed to allow military leaders to carry out the national strategy with a reasonable degree of success. In deriving the required force structure, constraints such as budget limitations, manpower reserve, material availability, industrial capability, and technology are considered. If the prudent risk force cannot be attained within the next five to seven years, the JCS must provide advice on the actions necessary to meet those deficiencies (Fairfield, 1979:56).

Based upon the previous studies conducted by the JCS, the Air Staff, and the major commands, the JCS, in fulfilling their obligation to provide advice to the National Command Authorities, publishes the Joint Strategic Planning Document (Fairfield, 1979:54). This document provides the advice of the JCS to the President, National Security Council, and the SecDef on the military strategy and force structure required to attain the national security objectives of the U.S. Published in November this document's purpose is to strongly influence the forthcoming Consolidated Guidance that will be issued by the Secretary of Defense (AFP 172-4, 1979:18). Contained in this document are:

1) Comprehensive appraisal of the military threat to the United States,

2) A statement of recommended military objectives,

3) The recommended military strategy to obtain the objectives,

4) Summary of the JCS planning force levels that could, with reasonable assurance of success, execute the military strategy,

5) JCS views on the attainability of the recommended force levels within fiscal constraints, manpower resources, material availability, technology, and industrial capacity, and

6) The initial appraisal of the risk associated with the programmed force levels (Command Magazine, 1979:8).

The purpose of this document is to provide the comprehensive recommendations of the JCS.

The planning cycle is completed the March after the issuance of the JSPD with the publication of the Consolidated Guidance (CG) by the Secretary of Defense. This document, issued after communications with the President, the JCS, and the Air Staff, presents the Secretary of Defense's views, interpretations, and priorities of the force structure recommended in the JSPD. The CG provides specific guidance in such areas as nuclear forces, general purpose forces, logistics, manpower, research and development, telecommunications, and intelligence and provides the rational for the defense program (AFP 172-4, 1979:13). Not only is the total obligation authority by service established in this document but also any other constraints that the SecDef wishes to impose. The CG provides the final guidance to the services for the preparation of the POM.

Mission Area Analysis

The aim of the mission area analysis (MAA) is to provide a basic understanding about what the Air Force needs to do in order to perform the missions assigned to it (AFP 172-4, 1979:20). Competing with other federal agencies for the available funds, the Air Force has to allocate limited resources in a multi-mission environment in trying to maximize combat capability. The MAA begins with the identified objectives listed in the JSPDSA Part 1 and ends with an output which shows how these objectives can be met. This process will aid decision makers at all levels to

1) recognize needs,

2) prioritize needs within mission areas, and

3) compare alternative solutions in terms of the marginal return each makes to combat capability (Fairfield, 1979:58).

MAA provides a mechanism for identifying the most critical aspects of the Air Force's mission and relates these aspects to the desired combat output and Air Force objectives. The results of the MAA are published in the Air Force Planning Guide (AFPR) which provides the criteria by which resource allocation alternatives can be assessed. The AFPG can be very useful during the POM development because it documents what the AF needs to do to meet current and projected deficiencies and provides a prioritized needs list which results from the MAA (AFP 172-4, 1979:20).

Programming Phase

The programming phase begins with the issuance of the Consolidated Guidance in March, continues through the POM exercise and submission, and ends with the SecDef issuing the Amended Program Decision Memoranda (PDM) in August (AFP 172-4, 1979:13). The Air Force Budget states that the main purpose of USAF programming is ". . . to schedule the application of current and projected USAF resources to the requirements of an orderly progression of aerospace capabilities essential to National Security Objectives [AFP 172-4, 1979:21]." USAF programming attempts to provide the minimum capabilities required to counter a perceived threat within the given resource constraints. The purpose of the planning phase is to convert Air Force requirements stated as needs and deficiencies to specific budget requests so that the President can submit his budget proposal to Congress.

During the programming phase, the SecDef provides the JCS and the Air Staff with the Consolidated Guidance which describes the SecDef's opinions and priorities for resource allocation in the Air Force. Based upon the CG, the Air Staff prepares the Air Force's POM which ". . . identifies resources required to perform assigned missions and distribution of resources to set up a balanced program consistent with fixed constraints established by DOD, OMB, Congress, etc. [ASD Pamphlet 800-19, 1979:49]." The JCS analyzes both the CG and the POMs submitted by the services and provides the SecDef with the Joint Program Assessment Memorandum (JPAM). The JPAM is the JCS's assessment of the capabilities of the POM force recommendations in meeting perceived threats.

Five Year Defense Plan

The Five Year Defense Plan (FYDP) is the official program summarizing the Secretary of Defense approved plans and programs for the Department of Defense (AFP 172-4, 1979:22). The FYDP details costs and manpower requirements for the budget year and the budget year + 1 through budget year + 4. Also, included for reference are the current and previous year requirements. It is updated three times a year: when the services submit their POM in May, when the budget submission is sent to the Office of the Secretary of Defense (OSD) for review in September, and when the President submits the budget to Congress in January (Fairfield, 1979:61).

The FYDP consists of both force-oriented programs and support-oriented programs and is continually being reviewed and modified in order to improve resource allocation to force-oriented mission programs consistent with DOD management needs and direction. Ten major force programs divide the FYDP as shown in Figure 4.

Program 1	-	Strategic Forces
Program 2	-	General Purpose Forces
Program 3	-	Intelligence and Communications
Program 4	-	Airlift/Sealift
Program 5	-	Guard and Reserve Forces
Program 6	-	Research and Development
Program 7	-	Central Supply and Maintenance
Program 8	-	Training, Medical and Other General Personnel Activities
Program 9	-	Administration and Associated Activities
Program 0	-	Support of Other Nations

Figure 4: Major Force Programs (AFP 172-4, 1979:23)

A program is defined as an aggregation of program elements which not only reflects a force mission or a support mission of DOD but also contains the resources needed to achieve an objective or plan. A program element describes a specific mission in terms of organizational ntities and resources such as forces, manpower, material, and cost required to perform the mission and is the primary data element in the FYDP (Fairfield, 1979:60).

Program Objective Memorandum

"The POM is used at the requesting level to project five year's requirements for dollars by mission or weapon system to update the Five Year Defense Plan (FYDP) [ASD Pamphlet 800-19, 1979:49]." The POM is based upon the guidance issued in the JSPDA2 and the CG and provides the detailed force structure and level of activity required to fulfill AF objectives within anticipated funding levels. Essentially, the process is one of fitting the next five year's forces within a fiscally constrained box (AFP 172-4, 1979:31).

Currently, the POM process starts the zero-base budgeting process in DOD for the federal government. Each program's description for the POM evaluation is written in the appropriate decision package format. Not only does the Air Force have to devise a force structure in the POM that will be able to meet any perceived threats but also the AF has to rank all the decision packages according to the rules of zero-base budgeting. The POM is related to the AF's budget in that the first year of the POM is the requested budget for the Air Force (AFP 172-4, 1979:31).

Feedback from the Air Staff's POM exercise is published in the Air Force P-series documents. These documents not only summarize the POM force structure but also capsulize the POM guidance items as they have changed from the last FYDP position. The P-series documents are the only formal system within the AF established in order to keep commanders informed of changes in the FYDP (Fairfield, 1979:67).

Joint Program Assessment Memorandum

Once the services have completed their POM requests, the JCS provide their input into the programming process by reviewing the POMs and providing their analysis in the Joint Program Assessment Memorandum (JPAM). This document contains the advice of the JCS to the SecDef for use in reviewing the POM, developing budget guidance, and deciding on specific programs (Command Magazine, 1979:7). The SecDef reviews the POM and the JPAM, and by communicating with the President, the JCS, and the Air Staff, the SecDef formulates the Program Decision Memoranda (PDMs) in August.

Program Decision Memoranda

The programming phase is considered completed when the Program Decision Memoranda (PDMs) or, if required, the Amended

Program Decision Memoranda, which represents the SecDef's basic program decisions, is issued in August (AFP 172-4, 1979:13). It incorporates all the program decisions through the SecDef's level and forms the basis for the budget proposal. From a budgeter's point of view, the PDM/APDM represents the approved resource (budget) levels reflected in the FYDP (Command Magazine, 1979:7).

Budgeting Phase

The budgeting phase begins with the issuance of the Budget Guidance in September and is completed when the President presents his budget in January. Budgeting as defined in ASD Pamphlet 800-19 is ". . . an allocation of programmed costs over time, the acquisition having been approved [ASD Pamphlet 800-19, 1979:49]."

> The budget is the culmination of the Planning, Programming, and Budgeting System. First, we plan, then having established objectives and goals, we program: fit resources to those plans. The last action is to budget: to calculate in detail the resources needed and available for our program [AFP 172-4, 1979:31].

After the Budget Guidance is issued, the Air Force develops its Budget Estimate Submission (BES) which the Office of the Secretary of Defense (OSD) and the Office of Management and Budget (OMB) review. The results of the OSD/OMB review are formalized by the Decision Package Sets (DPSs) which prioritize all DOD programs according to the rules of zero-base budgeting. The final step in the process is the Major Budget Issues (MBI) meeting between the SecDef, the Sec AF, and the Chief of Staff which is the Air Force's final formal appeal on behalf of its desired programs (AFP 172-4, 1979:33).

Budget Estimate Submission

The Budget Estimate Submission (BES) is the Air Force's statement of the funds needed to fund all the programs in the first year of the POM (AFP 172-4, 1979:31) and is based upon the base line developed in the PDM/APDM (Clark, 1979:75). It is submitted in a zero-base budget framework and consists of a minimum level and a series of alternative packages that are in priority order and which total to progressively larger budget totals (AFP 172-4, 1979:33). The BES is completed and submitted to OSD/OMB by October first and represents the AF's program priority structure within the budget limits established by OSD.

OSD/OMB Review Process

After the BES is submitted to OSD/OMB, it is divided up into specific areas for review by OSD/OMB comptroller staffs. The ultimate purpose of this review process is to develop the Decision Package Set (DPS) which will become the final guidance to the President when he is developing his budget for Congress. Each review group holds a hearing during which the Air Force can defend its particular position on the programs in question. At the end of the review process the OSD/OMB staff members are in a position to make the DPS decisions that could change the Air Force budget (Clark, 1979:82-84). If the Air Force does not accept the resource levels in the DPS, it can appeal the decision. After all the appeals are analyzed, the SecDef makes the final decisions and sends the DOD's budget to the President.

Development of the President's Budget

The final step in the PPBS cycle is when the President receives the DOD's DPSs and integrates them with all the other programs in the federal government. The result is the presentation of the unified federal budget in January to the Congress for debate. After ten months of debate, the budget is finally enacted by Congress in October (Clark, 1979:85-87).

Vanguard

Vanguard is a new planning process initiated by the Air Force Systems Command (AFSC) which will clearly show the contribution and interrelationship of each exploratory development, advanced development, engineering development, and acquisition project in AFSC. Decision makers, using the information provided by the Vanguard process, will be able to identify the need for modified emphasis on programs, changes in program schedules, or new technology developments. The results from Vanguard will be a prioritized list of efforts which will be used as an input to the AFSC POM and BES exercises (DCS/Plans and Programs, 1979:2-28).

ASD POM Process

One of the most important planning activities conducted at ASD during the fiscal year is the POM prioritization exercise because the results represent the ASD Commander's views on the programs that comprise his future business base (ASD/AV, 1980:15). Following the theory of zero-base budgeting, this prioritized list of programs is the view of the person who is held responsible for those programs. The list represents the ASD Commander's preference for which programs should be added if additional funds become available and which should be dropped if funds are cut.

The POM process is initiated when the ASD Comptroller receives POM guidance from AFSC Headquarters in mid-November. This guidance provides instructions on how the decision packages should be prepared and on what dollar figure should be used as the approved funding level. The program managers complete all the decision packages for their programs and submit the material back to the Comptroller's office. The Comptroller's office sends a copy of all ASD decision packages to ASD/XR. Mission Area Review panels are established and rank all the decision packages within their assigned mission area. The proposed rankings within each mission area are reviewed by the Program Review Group and finally, by the Decision Review Group which is chaired by the ASD Commander. After the Decision Review Group's review, ASD's input to the POM is sent to AFSC Headquarters and represents the ASD Commander's priority of programs within each mission area (ASD/AV, 1980:15).

At least four decision packages, minimum, decremented, approved, and enhanced, are required for each program. The minimum level is defined as the funding level below which it is not productive to continue the program (approximately 70 per cent of the approved level). The decremented level is the funding level between the minimum level and the approved level (approximately 90 per cent of the approved level) and may not permit the accomplishment of all the program objectives. The approved level is the AF approved funding level in the FYDP. Finally, the enhanced level is an increased funding level that is required in order to provide an earlier initial operation capability date, lower life cycle costs, or an increased capability. A fifth decision package could be submitted by the program manager and represents a special collection of projects which was not covered in the previous four funding levels (ASD Pamphlet 800-19, 1979:50).

Summary

The discussion about ZBB provides a theoretical base line for analyzing and discussing problems encountered by the DWMS panel when attempting to evaluate and rank decision packages for the 1982-1986 POM. The literature mentions five steps to the ZBB process, the information that should be available in order to evaluate each decision package, and the process recommended in order to institute major changes in an organization. The results of interviews with the DWMS panel members are presented in Chapter 4 and particular responses compared to the ZBB base line in order to analyze discrepancies and to suggest changes.

The PPBS used by the Department of Defense was also discussed in order to determine what documents are available for use by the Mission Area Review panels when reviewing decision packages for the POM. The BES, the Air Force Planning Guide, and the P-series documents would be appropriate to review in order to provide additional input information for the program evaluation process. The major problem associated with the DWMS mission area is that its programs support several of the other mission areas and cannot be related directly to the objectives of those mission areas. Chapter 3 contains a discussion of the factors involved when evaluating and selecting R&D projects.

Chapter 3

R&D PROJECT EVALUATION AND PROJECT SELECTION/ RESOURCE ALLOCATION PROCESS

The R&D project selection and resource allocation decision is a very complex process for any organization. The purpose of this chapter is to discuss the various factors which should be considered when evaluating an R&D project and various methods of using those factors to select the most beneficial combination of projects for the organization. Paolini and Glaser state that the choice of the appropriate project selection technique depends upon the nature and size of the research organization, its objectives and resources, and the type and quality of data available (Paolini and Glaser, 1977:26). The most important factor in considering and selecting any project evaluation and resource allocation model is the value of that model to the organization. If the benefits received from the model are not greater than the costs or if the model is too complex or requires an inordinate amount of time to collect the input data, the model is worthless to the organization. Bemelmans addresses a major problem in model development when he says that "there is no sense in using models, perfectly describing complex research situations, but at the same time so complex that an application would hardly be possible

[Bemelmans, 1979:38]."

A major disillusionment many managers have for highly quantitative models is that these models suggest a precision that is not there. Most of the input data are based on subjective evaluation by either an individual or a panel of experts. The accuracy of calculations is limited by the validity of the figures used in the computations (Roman, 1968:212). Paolini and Glaser state that management may be mislead by quantified models:

> Many managers believe that mathematical models and numerical formulas may tend to mislead by implying that quantifiable information is available that is more reliable and complete than is actually the case. The finite solutions obtained suggest a precision that doesn't exist [Paolini and Glaser, 1977:26].

Roman says that managers should not rely only on quantifiable information:

> . . . though the use of numerical evaluation gives an aura of mathematical accuracy to decisions which often makes them easier to justify to those who may review or question them, exclusive reliance on quantification can convey a misleading indication of both the relative and the absolute value of the overall project [Roman, 1968:212].

The following reasons are given by Roman as why quantification gives management only a general idea regarding project selection:

1) the quantification of data cannot guarantee the accuracy and relevance of that data, and

2) the quantification of data cannot be applied to the non-quantifiable elements which must be considered (Roman, 1968:212).

In evaluating and selecting an appropriate R&D project portfolio both quantitative and qualitative factors have to be considered in order to select the best possible portfolio for the organization. If the model captures enough of the problem, it can be a useful input into the allocation process.

The complex environment in which the R&D process is incorporated is depicted in Figure 5. Chiu and Gear state that the selection and allocation decision involves:

1) a variety of factors, some technical, but others organizational, behavioral, and economic:

2) multiple and conflicting objectives and priorities at various levels in the organization;

3) varying degrees of subjectivity in predicting outcomes of actions and estimating related probabilities;

4) complex sequential interactions between projects and with the "outside world" (Chiu and Gear, 1979:2).

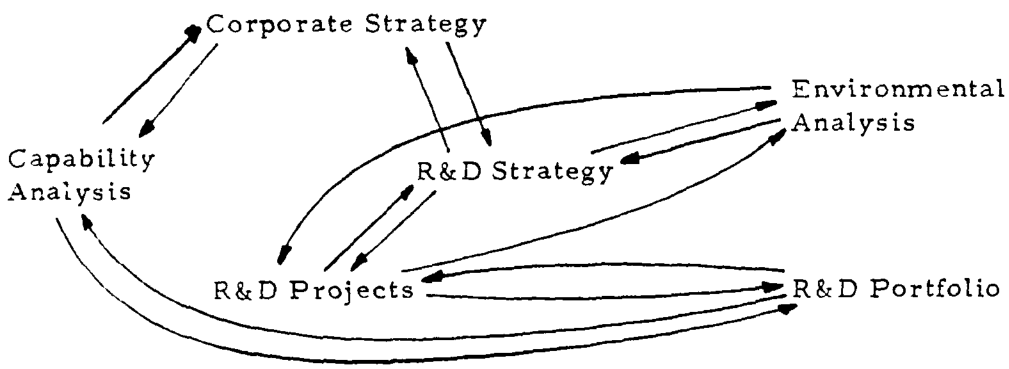

Figure 5: R&D Environment (Twiss, 1974:56)

A study conducted by Keeler determined that management felt that an evaluation/selection model could contribute to R&D planning. Management ". . . felt it could be helpful in achieving a consensus by functioning as a communication device and by stimulating and facilitating rational analysis on the part of those involved in R&D planning [Keefer, 1978:14]." Many organizations have become disillusioned and turned away from quantitative models because these models neglect or fail to evaluate many important qualitative factors. Baker speculates that the future importance for models will be away from "decision models" and towards "decision information systems" (Baker, 1974:169). Quantitative models will not be used to provide the final decision but will provide additional input information for the decision maker to evaluate along with non-quantifiable variables.

R&D Project Portfolio Concept

In order to maximize the benefits to the organization, the R&D project portfolio must be considered as a whole because the ultimate concern is not the individual project performance but the total benefit provided by the portfolio to the organization. The projects cannot be evaluated as independent entities because they compete for resources especially financial and are therefore interdependent. Twiss makes an important point when he states that:

> The aim of maximizing the contribution from the whole R&D portfolio may, therefore, occasionally result in the

> rejection of a project which might otherwise appear attractive because its high consumption of a particular resource leads to the starvation of other projects also requiring that same resource [Twiss, 1974:37].

Seiler discusses another possibility when a single large project may be dropped in favor of several smaller projects which have lower individual benefits but which provide a higher total benefit (Seiler, 1965:168). In order to efficiently use R&D resources, all projects should be interdependently evaluated to determine the best combination or portfolio of projects, rather than evaluating each project as a mutually exclusive entity.

Project Evaluation Criteria

Before a project can be evaluated, an appropriate set of criteria has to be established. Roman says that the criteria for selecting projects vary in degree of importance according to the nature and the need of the organization performing the evaluation (Roman, 1968:207). Beattice and Reader say that the project evaluation criteria must be based upon the particular organization's objectives and limitations (Beattice and Reader, 1971:50). If the evaluation criteria are not related to the goals and objectives of the organization, then the wrong portfolio of projects could be selected and resources will be wasted on projects that do not satisfy deficiencies of the organization.

Many authors have discussed the type of factors that need to be considered when evaluating R&D projects. Twiss lists five criteria: corporate objectives, strategy, policies, and values criteria; marketing criteria; R&D criteria; financial criteria; and production criteria (Twiss, 1974:122). Blake says that when evaluating any R&D portfolio the following multiple, conflicting criteria occur:

1) evaluation of proposed projects with respect to cost, feasibility, need, benefit, and motivation of people;

2) availability of personnel;

3) project risk;

4) management's resistance to risk and change;

5) technological forecasting--prediction of useful end result or advances in the state of the art;

6) biases in R&D estimates;

7) future costs; and

8) differences in perceptions between top management and R&D management (Blake, 1978:32-65).

Roman lists five main criteria: need satisfaction; urgency (immediacy of need/opportunity); predictability (degree of certainty); perceived future effect on savings in material, cost, or labor; and likelihood of technical success (Roman, 1968:166). Roman also says, that for military projects, mission accomplishment is of overriding concern and that military projects should be evaluated with respect to need, schedule, and anticipated performance (Roman, 1968:207).

R&D projects can interact in several different ways which is why it is important to evaluate and select a project portfolio rather than selecting projects just on their independent merit. Baker and Freeland in their review of project selection techniques state that one of the most important limitations of existing approaches is the "inadequate treatment of project interrelationships with respect to both value contribution and resource utilization [Baker and Freeland, 1975:1165]." Aaker and Tyebjee have suggested a technique which considers three types of interdependencies among projects. Their model is formulated to include adjustments to both the objective function and to the resource constraints (Aaker and Tyebjee, 1978:30-36).

The first type of interdependency is due to overlap in project resource utilization; projects utilize common equipment, personnel efforts, facilities, etc. The budget for such sets of projects would be less than if those projects were pursued individually. Second, two projects may be technically interdependent when the success or failure of one project significantly enhances or retards the progress of other projects. Finally, if the value contributions or payoffs for two projects are nonadditive, then those two projects are considered effect interdependent. Projects may have a synergistic effect where the benefits to the organization may be greatly enhanced if both are selected. Just as possible is that projects may have a cannibalistic effect where two projects are developing systems which compete with each other and the payoff if both are selected is much less than their summed payoff to the organization (Aaker and Tyebjee, 1978:30).

Several major criteria are common to all of the recommended evaluation criteria in the literature. All authors mentioned, in some form, the importance of considering long range organizational goals, risk, need, cost, technical performance, and project time phasing when evaluating projects.

Long Range Organizational Goals

The most important factor to be considered by management is how the R&D project relates to the long-range goals and objectives of the organization. R&D project objectives must be defined with respect to the goals and objectives of the organization so that the organization uses its limited resources in the most efficient manner possible in achieving those goals and objectives. Gee says that it is extremely important that the project goals are consistent with the organizational goals because the R&D projects have to be evaluated with respect to their potential contributions to those organizational goals (Gee, 1971:42). Twiss discusses the point that one of the most important qualitative criteria is, how does the project relate to the organization's objectives, strategy, policies, and values? He states that it is vitally important that strategic considerations be reflected explicitly in the project selection procedure (Twiss, 1974: 122). Whaley and Williams state that "without a clearly stated project objective, it will be difficult to determine whether the technical effort has met that objective [Whaley and Williams, 1971:27]." If the project selection process is to be decentralized, then Villers claims that "the long-range objectives of the company should be known to all those who make decisions. Otherwise, the research activity to a great extent, operates in a vacuum [Villers, 1964:20]." DeGreene discusses the problems in establishing the long range goals and objectives of an organization.

> Long range goals and objectives must be defined within the context in which the organization or system will exist. At a time of explosive, almost chaotic, change this is probably impossible for a rigid system. The job, then, is to build as much adaptability and flexibility into the system structure, function, and behavior as possible. At the same time, the job becomes even more complicated by virtue of: (1) demands for short-range benefits; and (2) the fact that industrial managers and political decision makers tend to perceive problems and goals in relation to their term in office; they are rewarded by accomplishing things today, not by having set the stage for a better organization or world tomorrow. There is thus the very real danger of near-range over exploitation of resources, resulting in greatly increased long-range costs to pay for short-range benefits [DeGreene, 1973: 173].

An R&D project has to be continually evaluated in terms of the current long range goals of the organization. Since an R&D project may last many years and budget decisions are usually made once a year, it is important to evaluate each project with respect to the current and future organizational goals not the goals when the project was initiated. Due to technological break throughs or policy changes, organizational goals can change over time.

Risk

R&D projects involve greater risk than other types of projects that an organization can undertake. Seiler discusses three types of risks associated with R&D projects. The first is the risk that the selected project may not be successful; that is, what is the probability of technical success of the project? The probability of technical success is a function of the state of the art in all fields relevant to the project being considered. The second type of risk is the probability that the project is successful but the need no longer exists once the project is completed. Since R&D projects take many years to complete, by the time the project is completed the original need may have changed. The relevant question here is, what is the probability of technical obsolescence during development? The last type of risk is the probability that a rejected project may have been successful if it had been selected (Seiler, 1965:129).

Another type of risk occurs due to the subjective nature of the input parameters that are used to evaluate each project and tends to produce biases in the R&D estimates. Blake states that biases enter into the estimation of the following parameters: probability of technical success, proposed development time, estimated development costs, and perceived need for the project. He says that the person doing the estimate usually has an incentive to estimate low in order to sell the project. Estimates of time and costs will probably never be accurate so decision makers should always keep in mind how poor their data is (Blake, 1978:57).

Need

An organization develops a long range strategic plan to provide direction to that organization for several years into the future. Along with developing that plan, planners project current capabilities into the future in order to determine if those current capabilities will allow the organization to achieve its strategic plan. If current capabilities fall short of the required capabilities, then a deficiency exists. Ranking projects and allocating resources according to projected deficiencies would not be the most efficient allocation of an organization's scarce resources. In order to determine an organization's need, the relative importance of satisfying each deficiency has to be considered. It would not be in the best interest of the organization to allocate resources to an area which has a large deficiency but is considered to be of little importance to that organization. Need is determined by multiplying the deficiency in a particular area by the importance to the organization of satisfying that need (Belcher, 1980).

Roman states that need satisfaction is one of the most important criteria in evaluating R&D projects and is of overriding importance to a military R&D selection process (Roman, 1968:207).

Costs

When considering the worth of any R&D project, the decision maker wants to maximize the future benefits per dollar spent on R&D. Because many R&D project estimates are highly variable, it is difficult to obtain an accurate estimation for costs. Since the R&D environment is so fluid, Blake states that in order to obtain an accurate reason for cost increases any changes in costs due to changes in the scope of the work must be separated from cost changes due to poor management, inaccurate cost estimates, or changes in material costs and direct labor rates (Blake, 1978:69). He also addresses the issues of sunk costs and project termination. Economic theory says that decisions should be made between alternatives that can affect the future and money already spent should not be considered. Considering sunk costs is not valid for deciding whether to spend more money on a project or to terminate that project. Bobis et al. state that expenditures to date should not be considered; therefore, each project must be reconsidered at budget time and that money already spent is gone. Anticipated returns are based only on the research expenditures that are still required and the potential effect of the project on future benefits to the organization (Bobis et al., 1971:36).

Time Phase

Most authors discussed the importance of considering the time phase of the R&D projects when determining the appropriate R&D portfolio. Seiler describes timing in terms of, will the funds be available when needed; and will the research be completed and the product be developed in order to satisfy the organization's need at the appropriate time (Seiler, 1965:138)? Roman says that timing is critical in determining the urgency of the project. If the need is immediate, then the project will receive a high priority and a large portion of the available funds (Roman, 1968:166). In the military environment timing is very important. Will the particular concept become an operational system in time to meet a perceived threat, or will a large amount of money be spent on a system which will be obsolete before it becomes operational?

Technical Performance

Of course when evaluating an R&D project, the technical specifications and changes to those specifications have to be considered. Will the end product be able to perform as stated in the project documentation? Gee states that the project should be evaluated with respect to the technical soundness of the proposal and whether it is within the current state of the art or requires a technological break through (Gee, 1971:42). Roman says that for a military project the anticipated performance is of major importance in determining whether the final product will be able to accomplish its mission (Roman, 1968:208). Within the DOD, at each milestone a major system has to be evaluated as to whether or not it is meeting the required performance specifications (DOD Directive 5000.1, 1978:3). If a project is not meeting the performance specifications and a more beneficial project is proposed, the original project should be terminated in favor of the new one.

Associated with the technical performance of a project is the question of what future developments might occur from the current research. Twiss identifies two types of future and unplanned benefits that may result from current research projects. Synergy between projects occurs when the research conducted on one project helps to solve problems on a completely different project. Lessons learned reports or informal meetings can pass along information that is beneficial to all researchers. Another result is that of project spinoffs. Research on one project may result in unforeseen benefits or applications to an entirely different field of technology (Twiss, 1978: 138).

Military Project Selection

Although many of the same type of criteria are important in evaluating both commercial and military R&D programs, there are substantial differences because military project ideas are developed in response to a perceived need rather than to a profit motive. Roman states that the most compelling force in project selection is the identification and justification of the need relative to the cost and the potential value of the project. He goes on to discuss four elements which must be weighed in the decision making process:

1) technologically feasibility,

2) expected military value of the system,

3) expected cost, and

4) value and cost compared with those of existing or other possible systems (Roman, 1968:213).

Fundamental in any weapon system decision are: the threat of a potential aggressor, the cost of the system, the existing state of the art, and timing. The state of the art not only determines the present ability to deal with possible threats but also the quality of the possible R&D. At any point in time and under a given circumstance, any one of the fundamental elements could dominate the selection process (Roman, 1968:213-220). Blake notes that military projects are characteristically more technological innovative and therefore greater risks are involved compared to civilian projects (Blake, 1978:53).

R&D Project Selection Techniques

Once all the R&D projects available to the organization have been evaluated and the perceived benefits determined, the next problem for the decision maker is how to select the best portfolio of projects given the resource constraints. Many models have been discussed that vary from a simple evaluation by one decision maker to complex mathematical programming models. As more people study the R&D selection process and as more accurate input data becomes available, more decision makers have turned away from qualitative models toward quantitative models. Another factor driving decision makers toward quantitative models is that as resources become more limited all organizations need to obtain the maximum possible benefit for each dollar spent on R&D.

Scoring Models

One of the o iginal methods for evaluating R&D projects was with a scoring model. Baker and Freeland state that in a scoring model it is assumed that a relatively small number of decision criteria can be defined to effectively evaluate the worth of each project. The criteria are related to specific characteristics of the project, and a group of experts determines the relative worth of each project. The vectors of relative worths from each expert are either summed or multiplied together to form a total score for each project. This total score represents the group's opinion of the relative worth of that project. Projects are ranked by their total score and included in the portfolio according to the priority ranking until some constraint, manpower, facilities, or budgetary, is exceeded (Baker and Freeland, 1975:1168).

Bemelmans lists three main advantages of scoring models. First is the consideration of both qualitative and quantitative data at the same time because both types of data are converted to a single number by the use of an interval scaled evaluation criteria. Secondly, scoring models are simple and easy to apply. Finally, it forces everyone to consider the same relevant aspects of the project (Bemelmans, 1979:38).

Three disadvantages are mentioned by Bemelmans. First, the scores suggest a precision that is not really there. The evaluation process is highly subjective, and therefore the results are highly sensitive to the opinions of the evaluators. Secondly, contending projects can not be evaluated in a detailed and refined way (Bemelmans, 1979:39). Harrington mentions that since the criteria ratings are combined into one total, dimensionless score, little analysis can be performed as to the degree that the resulting portfolio meets various organizational criteria (Harrington, 1979:16). The net result could be an undesired portfolio. Finally, Bemelmans mentions the lack of model structure between all evaluation aspects. Interrelationships and interdependencies between projects and criteria have a tendency to be overlooked or underestimated (Bemelmans, 1979:39). Another disadvantage is that once the budget constraint becomes binding the portfolio is selected. Scoring models neglect the possibility that by exchanging two rejected projects for one selected project, a better portfolio could result if the summed total benefits of the rejected projects are greater than the benefit of the selected project even though their individual benefits are lower.

Economic Models

Many economic models exist in the literature and have been tried with limited success. In one model, an index of relative worth, based upon economic criteria, is calculated for each project and then the projects are rank ordered according to this index. In some cases, a minimum index value is established below which the project is rejected. All projects above the minimum index value are selected based upon their ranking until the budget constraint is satisfied. Seiler discusses a profitability index which is a ratio of expected profit to expected total costs for the project. The probability of technical success is multiplied by the probability of commercial success, annual sales in dollars, and the expected market life and represents the expected profit of the project. The expected total cost is the sum of the R&D costs, the development costs, and the marketing costs (Seiler, 1965:16).

Other economic models are based upon the capital budgeting concept. Paolini and Glaser discuss models based upon either the internal rate of return (IRR) or the net present value (NPV) concept. The portfolio is developed by ranking all projects by either their IRR or NPV and including all projects up to the budget constraint. Although these concepts seem initially appealing especially to financially oriented managers, problems exist in estimating the appropriate interest rate and the expected benefits over time. The capital budgeting methods also neglect a factor which estimates the probability of technical success of the project (Paolini and Glaser, 1977:27).

Harrington lists three other disadvantages to economic models. First, only the budget constraint is considered in determining the project portfolio. Second, the models disregard noneconomic objectives of the enterprise and select projects based only upon economic criteria. Finally, no guidance is provided when two projects have the same index but have varying resource requirements over time (Harrington, 1979:19).

Mathematical Programming Models

Mathematical programming models are the most recent attempt at developing a decision model to aid managers in the R&D project selection process. Major advantages of these models over scoring models and economic models are that mathematical programming models select an optimal portfolio of projects rather than evaluating each project individually and the formulation allows projects to be constrainted by more than one resource limitation. For example, constraints due to manpower, facilities, and budget resources are possible with the mathematical programming models. In some cases, the portfolio may not be constrained by the dollars available but the organization may not have the laboratory facilities to handle all the proposed projects.

A linear programming (LP) formulation of the project selection decision has been formulated by Bell and discussed by Gear et al. (Gear et al., 1971:66). In Bell's model, each project or project version is represented by a variable that may take any value between zero and one. In the final solution, a value of zero represents a project that was not selected while a value of one represents total selection of that project. Any value between zero and one represents the fraction of that project which is selected. Other features of Bell's model are the consideration of the multiple time period nature of R&D projects and the possibility of multiple resource constraints on the optimal portfolio. Bell's formulation is typical of the LP approach to portfolio selection:

Maximize: $$z = \sum_{i=1}^{n} \sum_{j=1}^{m_i} b_{ij} x_{ij}$$

Subject to:

1. Resource Constraints

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} a_{ijkp} x_{ij} \leq A_{kp} \qquad k = 1,2,\ldots,N \quad p = 1,2,\ldots,P$$

2. Mutually Exclusive Project Versions

$$\sum_{j=1}^{m_i} x_{ij} \leq 1 \qquad i = 1,2,\ldots,n$$

3. Non-negativity

$$x_{ij} \geq 0$$

where:
n is the number of projects.
m_i is the number of versions of project i.
N is the number of resource categories.
P is the number of time periods.
b_{ij} is the value of version j of project i.
a_{ijkp} is the amount of resource k required by version j of project i in time period p.
A_{kp} is the overall availability of resource type k in period p.

Although LP formulations allow large problems to be efficiently and quickly solved, this formulation only makes sense when fractional parts of projects are feasible. In some cases fractional projects could be included in the research effort as partial versions of the original projects. Harrington discusses Asher's claim that this approach shows that some work should be accomplished on the project in the current period rather than eliminate the project which would allow slack to occur in the binding constraints. Several authors mention the possibility of rounding the fractional value to the nearest integer value, but that is dangerous because it could result in either an infeasible or feasible but not optimal solution (Harrington, 1979:22). One important advantage to the LP approach is that much useful information such as shadow pricing, right-hand side ranging, and benefit row ranging can easily be obtained through sensitivity and postoptimality analysis (Gear et al., 1971:67).

Since in some cases fractional projects do not make sense or management may not mind resource slack in the uncertain, dynamic R&D environment, the LP method may not be the proper approach to R&D project selection. A 0-1 integer programming (IP) formulation may be the appropriate approach. Paolini and Glaser discuss the R&D project selection problem formulated as a 0-1 IP model where the variable, x_{ij}, is further constrained as follows:

$$x_{ij} = \begin{cases} 1 & \text{if version } j \text{ of project } i \text{ is selected,} \\ 0 & \text{otherwise,} \quad i = 1,2,\ldots,n, \\ & \qquad\qquad\quad j = 1,2,\ldots,m_i \end{cases}$$

(Paolini and Glaser, 1977:27).

Additional constraints can be formulated to allow for the inclusion of compulsory projects, compulsory projects with lower bounded project versions, alternate compulsory projects, and mutually dependent projects.

The major advantage of the 0-1 IP approach is that it eliminates the problem of selecting fractional projects. The major disadvantage is that existing solution algorithms are relatively very time consuming when solving large problems. Another disadvantage is that in order to perform sensitivity analysis the complete problem has to be rerun (Harrington, 1979:23).

Multicriteria Models

One of the major disadvantages to either the LP or 0-1 IP formulation discussed so far is that they do not explicitly consider the multiple, conflicting nature of organizational goals. The multiple goals are reduced to a single objective, which is usually economic, for optimization. McMillan states that managers tend to set goals and then seek that allocation of resources which offers the best promise of achieving those goals. It is possible all the goals that have been established lie outside the feasible region for the given constraints, and therefore, no goals can be achieved exactly. Management would then seek that solution which minimizes the deviations from those established goals (McMillan, 1975:588-589). If management can establish an ordinal ranking for noncommensurate goals, then a goal programming (GP) formulation can be used to solve the

R&D project selection problem.

The concept of goal programming is that a quantifiable goal is set for each of the multiple objectives relevant to the problem being analyzed. Next, preemptive priorities are established for each goal in order to preserve the ordinal goal ranking established by management. The preemptive goal priorities assure that lower priority goals will only be addressed after higher priority goals have been satisfied as best as possible. With multiple goals, all goals usually cannot be achieved exactly. Goal programming seeks that solution which comes as close as possible to satisfying all of the quantified goals by allowing under and over attainment of goals. Harrington discusses the application of 0-1 goal programming to the selection of an R&D project portfolio (Harrington, 1979:1-160).

Besides the advantage of allowing for multiple, conflicting goals, goal programming allows sensitivity analysis to be performed on the preemptive goal priorities themselves. Management can easily change the goal priorities and evaluate what effect that chance has on the final R&D project portfolio. Possibly management is uncertain about what the actual priorities should be and sensitivity analysis would allow them to determine those goals to which the portfolio is the most sensitive. Also, this analysis could aid management in determining the best R&D strategy for the organization to follow.

Multiperiod Project Modeling

Since R&D projects usually last more than one time period, the sequential, multiperiod nature of the projects should be accounted for in the project selection, resource allocation problem. Hess' model uses a dynamic programming approach to allocate resources between projects now and in the future. A major disadvantage of the model is that budget constraints in periods other than the first are not considered. Secondly, the only resource constraint that is considered is the budget. Facilities and manpower are not considered (Gear et al., 1971:72). Harrington discusses a project tree format that accounts for the multiperiod aspect of R&D projects. The project tree represents the evolution of projects or project versions and resource requirements and is used to develop the constraints for a linear or integer programming selection technique (Harrington, 1979: 25).

0-1 GP Approach to ZBB

McLaughlin et al. discuss a 0-1 goal programming approach to the selection of decision packages during the zero-based budgeting process for a federal agency. During the ZBB process, at least two mutually exclusive levels of effort (decision packages) are developed for each possible project. Each level of effort consumes a different amount of the available resources and provides a different level of benefits to the objectives of the organization. Since all projects are competing for the same limited resources, the projects are interdependent with respect to the total value of the possible portfolio. Traditional ranking methods based upon the use of expert panels and scoring methods have neglected this interdependency. The advantage of McLaughlin's approach is that it does allow for project interdependencies and selects the best portfolio of decision packages based upon the preemptive goals established by the organization (McLaughlin et al., 1980:1-27).

Although McLaughlin et al. formulate their model as a 0-1 goal programming model, the same problem can be reformulated as a 0-1 integer programming problem by maximizing only one objective--maximize the expected benefits to the organization from the project portfolio. The 0-1 IP can be formulated very similarly to Bell's LP formulation except that m_i is the number of decision packages for project i, b_{ij} is the value of decision package j of project i, a_{ijkp} is the amount of resource k required by decision package j of project i in time period p, and x_{ij} can take only the values of zero (decision package j if project i is not selected) and one (decision package j if project i is selected).

Summary

This chapter discussed many of the factors that should be considered when evaluating R&D projects and different project selection techniques which can be used to select the best project portfolio for the organization. Before these concepts are used to develop a project evaluation and resource allocation model for the DWMS review panel, a detailed discussion of the DWMS mission area and the comments of the DWMS panel members who were interviewed are presented in the next chapter.

Chapter 4

DEFENSE WIDE MANAGEMENT AND SUPPORT MISSION AREA

The Defense Wide Management and Support (DWMS) mission area is one of the ten mission areas defined in the AF Systems Command Vanguard documentation (DCS/Plans and Programs, 1979:9). The programs in this mission area provide a support function for the other six mission areas and help contribute to the objectives of those mission areas. During the POM ranking process, the DWMS mission area programs are the most difficult to evaluate and rank because of their interdependence with the other mission areas. There is no explicit statement tying DWMS programs to combat mission area deficiencies. This chapter describes the type of programs included in the DWMS mission area, the composition of the 1982-1986 POM DWMS Mission Area Review panel, and the results from a survey which investigated members' attitudes towards and recommended improvements for the DWMS POM ranking process.

Defense Wide Management & Support Mission Area

The DWMS mission area has two main objectives. The first objective is to provide support functions which are common to more than one combat mission area. The second objective is to improve the quality of that support and to reduce operation and maintenance costs. Programs proposed to meet these objectives must be evaluated and justified on the basis of their contribution to the accomplishment of combat mission areas goals. These support programs must be evaluated in terms of the effectiveness and efficiency/economy they provide to the combat forces (Weber, 1980a).

The type of programs included in the DWMS fall into nine major types of activities.

a. Studies and Analysis. These programs provide funds for development planning studies to assist in identifying and selecting the more promising approaches to needed capabilities.

b. Acquisition Support. These programs provide funds for telecommunications, civilian pay, travel, and other overhead associated with weapon system acquisition and command support roles.

c. Test and Evaluation. This activity provides for the operation, maintenance, and improvements for the 4950th Test Wing at Wright-Patterson AFB.

d. Safety/Protection. These programs address:

(1) Our capability to withstand and recover from overt or covert conventional attack.

(2) Protection from chemical/biological agents while sustaining essential operations.

(3) Improving the physical security of mission essential facilities/weapons/alert aircraft.

(4) Life support equipment for manned aircraft and hazardous ground environments.

(5) Aircraft escape/descent equipment.

(6) Personal survival/recovery equipment.

(7) Improved aircraft firefighting equipment.

(8) Survivability/vulnerability testing/assessment/design of aeronautical and communications equipment in a nuclear warfare environment.

(9) Examination of new concepts of threats for defensive consideration as well as offensive exploitation.

e. Mission Effectiveness. These programs enhance capabilities through aircraft non-nuclear survivability considerations and systematic incorporation of evolving technology in aircraft engines, and consolidation/automation of aircraft test equipment.

f. New Capabilities. The next generation trainer aircraft.

g. Equipment Improvement. These programs address improvements in current operational systems and facilities to correct identified deficiencies.

h. Other. Contingency funding for future R&D options (Weber, 1980a).

The DWMS mission area panel has to contend with a major problem when evaluating the DWMS program elements (PE) against each other in order to make project tradeoff and resource allocation decisions. Not only can one DWMS PE support more than one project in a specific combat mission area but also a DWMS PE can support several projects across combat mission areas. Some DWMS PE's contribute directly to the achievement of the goals for the other mission areas while for other DWMS PE's the goal relationship is vague and imprecise. Suver and Brown state that problems can occur when management tries to compare outputs of non-related decision packages as is required in ranking DWMS decision packages (Suver and Brown, 1977:81).

Another problem is that a DWMS project can contain all three of the project interdependencies as discussed by Aaker and Tyebjee (Aaker and Tyebjee, 1978:30). Many of the program elements deal with essentially very similar systems and problems, and if information was passed between program elements, synergy would increase the benefits to the AF. A DWMS project may be technically interdependent upon a laboratory's basic research results. If the laboratory's project fails, the DWMS project should not be funded. How can one effectively evaluate two completely different types of program elements which involve completely different technologies when the relationship between organizational goals and DWMS programs' objectives are not clear?

Categories of DWMS Program Elements

The DWMS PE's can be grouped into several different categories depending upon the type of program and guidance provided by higher management. The first category includes "level of effort" projects. These projects have a high return on investment, low or negligible technical risk, and the number of projects that are funded depend upon the level of funding approved for that program element. The next category of projects include the compulsory projects. These are either "letters of agreement" projects or projects for which the appropriate decision package is specified by higher management. "Letters of agreement" projects are joint projects with another unit of the AF, another service, or any other agency, and the AF has committed itself to a certain level of funding support. The third category consists of three management and support program elements. These PE's provide the funds for ASD telecommunications, ASD overhead, and the 4950th Test Wing overhead. The last category of programs are acquisition and development programs in support of the combat mission area objectives and have varying degrees of technical risk and return on investment. With such a wide diversity of programs, it is a difficult process for the DWMS panel to evaluate and rank all the program elements' decision packages according to their contribution to AF objectives for the ASD POM input.

DWMS Mission Area Review Panel

The purpose of the DWMS Mission Area Review panel is to evaluate and priority rank all the decision packages within the mission area according to their benefits to the AF. This evaluation and priority ranking process is the first step in the federal government's zero-base budgeting process. The benefits to the AF of each decision package have to be determined by the panel based upon project information provided by the program managers and AF goals, needs, and deficiencies provided by AF PPBS documentation.

Because this mission area contains such a diverse set of project types from which to select a portfolio, the panel of experts, which was chosen to evaluate the projects for the 1982-1986 POM, consisted of a representative from each major organization which had a program in the DWMS mission area. The panel was composed of ten people: eight representatives from each organization, a chairman, and a vice-chairman. The chairman and vice-chairman had a general overview level of knowledge about the programs rather than detailed knowledge about any one program. The eight representatives had detailed knowledge about their organization's programs but little to no knowledge about the other programs in the mission area. Suver and Brown make the point that the managers whose packages are being ranked should be members of the evaluation panel so that if their project is cut from the budget they will fully understand the justification for that cut (Suver and Brown, 1977:78).

Previous experience in the POM ranking process ranged from none to three years. Three members had never heard of zero-based budgeting; four members had heard of it and had limited knowledge about ZBB concepts; and three members had a good working knowledge of the ZBB philosophy. However, none of the members had had any formal training in ZBB procedures prior to the formation of the panel. Cheek recommends that top management provide detailed guidelines and training to the people who will be performing the ZBB process before the process begins (Cheek, 1978:24). Without the training and guidelines, there is no guarantee that the decision packages recommended to top management will provide the best portfolio of projects in order to meet the organization's objectives.

An important factor in the success of the DWMS panel was the experience of the panel members. All members had many years of experience in the acquisition process at ASD and were key members in the organizations which they represented. Intuition by the panel members was an important factor in the decision process.

DWMS Interview

Since the DWMS panel was comprised of members with a wide range of experience in the ASD POM process, an interview was designed and conducted in order to discuss the panel members' views about the 1982-1986 POM process. The questions were designed in order to refresh the members' memories about the procedures the DWMS panel used in evaluating and priority ranking decision packages, to discuss the pros and cons of the procedures used, and to discuss recommended improvements in future POM evaluation processes. It was important to evaluate whether the panel members understood the philosophy and purpose of ZBB and the POM ranking process and the importance of the POM to not only ASD but also the whole AF.

The interview was, also, used to evaluate the degree of consensus and consistency between panel members with respect to the purpose of the panel, the evaluation criteria, and the procedures used to evaluate and rank decision packages. Two types of consistency are important: internal consistency and external consistency. Internal consistency pertains to the same panel member evaluating all decision packages in the identical manner. External consistency addresses the question of whether two or more panel members evaluate the same decision package in the identical manner. In order to obtain a precise evaluation of all decision packages, the evaluation process has to be both internally and externally consistent.

DWMS Interview Questions and Responses

Nine of the ten DWMS panel members were interviewed and their answers to specific questions are discussed below. The first question discusses the procedures used by the DWMS panel in obtaining the final ranking of DWMS decision packages.

1. What is your recollection of the steps that the DWMS mission area panel went through last year in order to technically rank decision packages for ASD's input to the AF POM?

During the first meeting after the panel members were assigned from their respective organizations, the group discussed the ground rules for the evaluation process, the proposed evaluation criteria, and the schedule of events. This procedural review was conducted before the group began to review the decision packages and was helpful in increasing group internal and external consistency. New members were especially appreciative of this meeting because they had received no formal training in either ZBB or the ASD POM process. This initial meeting was the first contact that several of the new members had had with ZBB and the ASD POM process.

The evaluation criteria from the 1981-1985 POM cycle were reviewed and improved. Consensus of opinion was obtained on the definition of the resulting evaluation criteria and how each decision package would be evaluated. All members of the group were satisfied with the final evaluation criteria and evaluation process. One member stated that there may have been other ways to evaluate the decision packages but this method will suffice. Morris states that in making policy decisions managers don't seek to maximize or minimize but seek to "satisfice" (Morris, 1977:588). The final evaluation criteria are shown in Figure 6.

- Importance
    - Effectiveness
        - Mission Accomplishment
        - Survivability
        - System Improvement
    - Efficiency/Economy
        - Life Cycle Costs
        - Standardization
        - Training
- Uniqueness
- Reality

Figure 6: DWMS Program Evaluation Criteria (Weber, 1980a)

The scoring model methodology that the panel would be using was reviewed. Each panel member would subjectively evaluate each decision package as to its contribution to AF goals using the evaluation criteria effectiveness, efficiency/economy, uniqueness, and reality. The ordinally scaled benefits for each criteria ranged from one (high) to three (low). An individual's total score for one decision package was obtained by summing the individual's scores for each criterion. Then, all ten member's individual total scores were summed in order to obtain the total benefit of that decision package to the AF.

An implicit assumption made by the DWMS panel was that in determining the total benefits of each decision package, all decision packages were considered independent R&D projects. The fault with this assumption is that all decision packages for the same program element are interdependent. ASD/ACB letter, 16 Nov 1979, "FY 82-86 POM Submission," requires all decision packages to be written on an incremental basis (ASD/ACB, 1979:49), i.e., DP2 includes DP1 and DP3 includes DP2 and DP1. Therefore, the benefits to the AF from each decision package should be evaluated on an incremental basis. What additional benefits to the AF are incurred by selecting DP2 over DP1 or DP3 over DP2?

Finally, during the first meeting, the panel decided that each program manager should be allowed to present a short briefing in order to defend his program and to answer questions. Several important factors entered into this decision. First, the time in which to evaluate approximately seventy decision packages was extremely limited. Second, four out of the ten members were new to the POM ranking process. Finally, each panel member had expertise only in the projects from that member's organization. By having the program managers available to defend their program, any questions that were not answered by the decision packages could be answered by the program manager.

At the end of the first meeting, the panel members were given a copy of all the decision packages within the DWMS mission area. During the next two days, they had to review all the decision packages and prepare questions for the program managers. After the program managers discussed their programs and answered the panel's questions, the panel members had another two days to evaluate all decision packages and determine a total score for each decision package using the scoring model previously discussed.

When the complete DWMS panel reconvened, the total benefit for a decision package was calculated by summing each panel member's individual total score for that decision package. Any large inconsistencies as shown by a large variance in individual total scores for a particular decision package were discussed so that the members could be in complete agreement with the final evaluation. Then, the initial decision package ranking was obtaining by ordering all the packages according to their total benefits. At this time, the interrelationship between decision packages for the same program element was considered. If DP2 was ranked higher than DP1, then DP1 was dropped off the list since DP2 included DP1. Similarly, if DP3 appeared above DP2 and DP1, then both DP2 and DP1 were dropped.

Next, using the intuition of the panel members, the initial ranking was reviewed to determine if it seemed to be "reasonable" to all the panel members. ASD overhead DP3, 4950th Test and Evaluation Squadron overhead DP3, and ASD telecommunications

DP3, although in the "definitely funded" category of projects but not the top three decision packages, were moved to the top three positions.

Once the panel members were in complete agreement on the priority structure of the decision packages, the estimated funding level was included in the analysis. This figure is either the summation of all the DP3's for the approved programs in 1982 from the Five Year Defense Plan or is provided by higher headquarters (ASD/ACB, 1979:1). Next, the cumulative cost total for the decision package priority structure was calculated starting with the number one priority DP and continuing through the last DP. All decision packages, whose cumulative total cost was below the budget figure, were in contention for recommendation to the Program Review Group for being included in ASD's input to the POM.

Before the final portfolio was recommended, the DWMS panel reviewed the programs which were just above and just below the budget line. The purpose of this review was to determine, based upon the panel's intuition, if a better portfolio could be obtained by moving one project below the funding line and several smaller projects above the line. After the DWMS panel arrived at a final consensus on the priority structure for the decision packages, this ranking was recommended to the Program Review Group for their review and evaluation.

During the initial interview with the DWMS panel chairman, he stated that the POM process is a "technical ranking" of decision packages (Weber, 1980a). In order to evaluate the degree of consensus within the DWMS mission area panel as to the definition of "technical ranking," the following question was asked.

2. What is your interpretation of the words "technical ranking" as used to describe the POM ranking process?

All of the panel members agreed that the POM ranking process was not a pure technical ranking; the major question was not whether the decision package could be technically achieved but rather how much does this decision package contribute to satisfying AF needs and deficiencies. The question asked by DWMS panel members was, how would I rank this decision package against all others in this mission area based upon its contribution to the objectives of the AF both now and in the future?

Agreement was not obtained on whether project cost should or should not be considered in defining "technical ranking." One member stated that the initial ranking should be conducted without considering the cost of the programs. Another member stated that the cost of a program is very important and should be considered because one very good program may require the majority of the available funds. Twiss comments that the whole R&D portfolio needs to be maximized which may result in excluding a high value project because of its high consumption of the available resources (Twiss, 1974:37). Another member mentioned that all projects should be ranked using benefit-cost analysis. Finally, one member stated that return on investment (ROI) should be used to help rank programs. The problem with the use of ROI is that some of the "level of effort" programs required a minimum ROI of 20 to 1 before being undertaken while the ROI for other program elements would be impossible to determine.

The following six questions were aimed at an in depth analysis of each member's understanding of the purpose of the DWMS mission area and the objectives of the DWMS programs, of the available information about each decision package, and of the evaluation criteria and other influential factors.

3. What is your interpretation of the purpose and objectives of the DWMS mission area?

The purpose of the DWMS mission area, according to the panel members, was to provide a mission area for those programs that support several other mission areas or whose descriptions do not conform to the definitions of programs contained in the other mission areas. Some very small projects, which were needed in order to support the objectives of the combat mission areas but were too small to compete for funds alone, were combined with other similar projects into one program element which was competitive within the DWMS mission area. Since many of the projects support many or all of the other mission areas, it would not be practical to breakup the projects so that a portion would be funded by the mission area which it supported. One panel member commented that some of the DWMS programs provided needed capabilities that would not be funded in another mission area. Another panel member commented that several programs were placed in the DWMS mission area because higher management felt that these programs could compete more easily for funds in the DWMS mission area.

4. Was it clear how the DWMS decision packages contributed directly to satisfying Air Force needs and deficiencies, or if not directly, then indirectly, through support of programs in other mission areas?

All panel members stated that it was not clear hcw the DWMS decision packages contributed to satisfying AF needs and objectives. The members had to rely on their intuition, experience, and subjective judgements in order to relate the DWMS programs to AF goals. One member stated that the problem was caused by the DWMS programs having only second and third order relationships to AF goals by aiding programs in other mission areas achieving the goals of those mission areas. Several members commented that a short briefing on the goals and objectives of ASD, AFSC, and the AF over the next fifteen years as well as the SecDef's direction for the AF would aid in the decision process. McCandless states that the initial step in the ZBB process is for top management to provide lower management with the strategic plan of the organization and the assumptions used in deriving that plan (McCandless, 1978:46). The problem at ASD was that although AF and DOD do provide planning documentation, the documentation is either not readily available; to voluminous to be analyzed in the short time available for the POM ranking; or as in the DWMS mission area case, provides only scattered and partial information relating projects to AF needs.

Several members commented that many decision packages were written so that the objectives of those decision packages were not related to deficiencies of the AF. Another comment was that the objectives of a decision package were written with respect to the AF needs when the project was started, not the current needs of the AF. The decision packages' objectives should be related to the strategic goals of the organization. ASD/ACB letter, dated 16 November 1979, stated that the long range capability goals of each decision package should be directed towards the general need of the AF (ASD/ACB, 1979:32). Letzkus states that the objectives of a program must be continually evaluated because of the dynamic nature of the AF environment causing AF needs, requirements, and objectives to change over time (Letzkus, 1978:38). All of the panel members stated that the program manager's briefings were extremely important because questions concerning the individual programs could be answered at this time. Finally, one member stated that if the decision packages for a program were clearly related to AF needs, it was easy to evaluate the program's value. It appears that a briefing to the program managers concerning AF goals and objectives before the decision packages were prepared would help to standardize the information contained in the decision packages.

5. To aid in evaluating each decision package with respect to AF goals, what additional type of input information would you have liked to have had available and would like to see in the future?

All members stated that they would have liked to have available the documents which authorized the programs. The Statement of Operational Need, the Mission Element Needs Statement, or the Program Management Directive would provide additional information justifying each program. A better definition of the requirements that the decision package were suppose to satisfy as well as a brief summary of how this decision package contributed to the current direction of the Air Force would aid the panel in its evaluation process. One panel member stated that several decision packages seemed more like marketing brochures rather than a concise, technical description of where the program is and where it is going. Although Burroughs says that each decision package should include performance measures for evaluating the effectiveness and efficiency of the proposal (Burroughs, 1977:8), Suver and Brown state that for public programs, such as national defense, output measurements in terms of achievement are either too subjective, lacking, or too argumentative (Suver and Brown, 1977:81). It is very difficult to measure the output in terms of increased national security from a DWMS program and more program documentation is not the solution. Several members commented on the fact that they could not read and absorb all the information already provided in the decision packages and relied mainly on the Decision Unit Overview and Decision Unit Summary forms for information. Increasing the guidance and providing training to the program managers on decision package preparation would increase the quality and consistency of the decision packages which would provide all the required information for effective evaluation.

6. With respect to the input information that was available, what factors did you consider the most important?

Concerning the evaluation criteria, all panel members felt that effectiveness was the most important followed by efficiency/economy although in the scoring model all evaluation criteria were weighted equally. Effectiveness is concerned with the accomplishment of stated objectives while efficiency assess these accomplishments in terms of the resources used. Effectiveness is especially significant in the military R&D project selection decision where a profit motive is lacking because the ultimate test for the success of a project is the ability to accomplish the required mission.

Several members mentioned that the program manager's briefings were invaluable because this was an opportunity to ask questions in order to gain information, not provided in the decision packages, about the programs. Finally, one panel member mentioned the political realities involved with a particular program. It did not make sense to recommend a program to be funded knowing that it would not be supported by higher management.

7.a. What is your interpretation of each evaluation criteria?

b. Do you feel that this set of evaluation criteria was sufficient to realistically evaluate each decision package with respect to its ability to meet projected Air Force needs? If not, what evaluation criteria would you recommend?

c. What type of questions do you feel effectively evaluate each decision package with respect to the listed criteria?

Importance was considered to be comprised of two subcriteria, effectiveness and efficiency/economy. Effectiveness pertains to mission accomplishment, which may be the most important consideration in a military environment. Also, considered under effectiveness were the survivability of the system in a combat environment, and the question, does this project contribute to the improvement of a combat weapon system? Effectiveness was described by the question, how well does the decision package fulfill its objectives, which are related to AF needs?

Efficiency/economy evaluates the life cycle cost, standardization, and training requirements of the decision package. The questions asked with respect to efficiency/economy were, given that the decision package is effective, is the job being accomplished for the least cost, or does the package contribute to the standardization of other programs? With Congressional interest on military spending, reducing system life cycle cost and increasing standardization between systems is receiving greater importance in project evaluations.

The following is a list of questions which the panel members used to evaluate the uniqueness of a program. Given that the program is important, is the DWMS mission area the only funding source for the program? Is this project the only effort being conducted by DOD to satisfy a requirement or correct a deficiency? Is this a "one of a kind" AF project which is needed, but if it is not funded in the DWMS mission area, it will not be accomplished? Is any other DOD agency performing the same work or is the DWMS mission area the only mission area in which this work is performed? Finally, is this a joint agency project where there exists a "letter of agreement" between the AF and another federal agency which states that the AF will provide a certain level of funds? Rather than being considered as an evaluation criteria, uniqueness could be included in an R&D project selection model as a compulsory project with a lower bounded decision package.

The last evaluation criteria, reality, evaluated how realistic the project is in the current political, economic, technical, and threat environments. A very important factor in evaluating any project is the political support for the project. Who is the champion of the project? Does the project have organizational support? Based upon each member's intuition, does the decision package documentation clearly justify the project so that it has a high probability of being funded? If a project is dropped at higher management levels, those funds may be lost because another project may not be substituted.

Several members mentioned the importance of considering the technical feasibility and risk of the project. Risk occurs due to the uncertain nature of the outcome of an R&D project (Seiler, 1965: 129) and due to the subjective nature of the input parameters used to evaluate an R&D project (Blake, 1978:57). What is the probability that the project, if funded, will be a success? Is the project based upon current state of the art, or does it depend upon the technological efforts in a laboratory? Time and effort are wasted in evaluating projects for inclusion in the budget if there is a high probability or certainty that the underlying technology will not be available from the laboratory for several years or if the laboratory does not plan to fund the required technology. The program managers should include in their decision package submissions any changes that have occured in the initial estimates of when technology will be available from the laboratories. The dependency of a DWMS project on laboratory technology can be included in an R&D project selection model as a mutually dependent project constraint with the laboratory program element considered a mandatory project if selected by the laboratory's ranking process.

Several members stated that cost versus time and cost versus payoff were important considerations when evaluating the reality of a project. Is the project schedule realistic? Can the project be completed in the stated time for the stated cost, or is there a high probability that the program will slip resulting in cost overruns? Are the future costs, as presented in the decision packages, realistic? Will funding a project now result in a large increase in funds required in the future? Do the benefits received from the project justify the cost, or should the funds be used to support another project which has a higher contribution to the goals of the AF? Harrington discusses a decision tree format which includes the multiperiod aspect of R&D projects in a mathematical programming model (Harrington, 1979:25). The five year funding requirements for a project as expressed in the FYDP can be formulated as constraints in a selection model.

Lastly, several members mentioned the possibility that a project could be tied to a multiyear contract. If the project is required to be funded at a stated level, a compulsory project with a lower bound decision package constraint can be included as a part of a selection model.

8. Concerning the overall POM ranking process, what type of external pressures and factors were present and should be included in the evaluation process?

Most of the panel members remarked that external influences were minimal to non-existent throughout the evaluation process. The panel did not try to second-guess higher management and tried to provide their best judgement on the programs with full justification for their approval or non-approval of any program. One member did state that external influences were included in the evaluation process under the evaluation criteria, reality. Another member said that it was impossible to operate in a vacuum and not be influenced by external factors especially when it was general knowledge how top management feels about certain DWMS projects. According to the philosophy of ZBB, each level of management is supposed to evaluate each project based upon its contribution to organizational goals and not upon lower management's perceived desires of top management. Top management provides the long range goals of the organization, and lower management provides a project priority ranking based upon their evaluation of each project's contribution to those organizational goals.

The next three questions discuss the DWMS panel members' views on the major problem areas encountered, strengths and weaknesses of the ranking process that the DWMS panel used, and recommendations for the future.

9. With respect to the overall objectives of the DWMS panel, what were the major problems encountered in the ranking process?

The major complaint from the panel members was that there were too many decision packages to properly review and evaluate in the amount of time available. Only about a week and one half was available to review, evaluate, rank, and justify about seventy decision packages. The panel members that had never been involved with the POM ranking process said that the process was extremely difficult for them because they not only had to review all the decision packages but also had to learn the POM process philosophy before an adequate job in ranking packages could be performed. All members stated that more time was needed in order to fully evaluate all the decision packages and to make accurate tradeoffs between them. Anthony (Hyde, 1978:322) and McLaughlin et al. (McLaughlin et al., 1980:2) suggest that the program evaluation process could take place more effectively outside the budget cycle when there does not exist a heavy workload and deadlines.

10. What do you feel were the strengths/weaknesses of the approach that the DWMS panel used to technically rank decision packages?

The major strength mentioned by the panel members was the efficiency with which the DWMS panel was run. The administrative procedures were very well preplanned and little time was wasted before the actual evaluation process began. One panel member did comment that a better definition of the evaluation criteria would have been helpful because valuable time was used to discuss and define the criteria.

Three major weaknesses were noted by the members, all of which dealt with the external environment imposed on the panel by ASD rather than the procedures used by the DWMS panel. First, as previously discussed, there was a very limited amount of time available in which to evaluate the decision packages. Many members felt that the review process was not as thorough as it should have been because of the time constraint. Second, the decision packages did not contain enough detailed information by which adequate tradeoffs could be determined. Finally, there was a high variance in the quality of information contained in the decision packages which made it extremely difficult to evaluate entirely different types of projects.

12. What improvements would you like to see incorporated into the ASD POM process in order to improve the quality of the output?

The first recommended improvement stated by all of the members was to increase the amount of time available to review the decision packages. Since the people at ASD know that the POM ranking process occurs every year and during the same time period, the program managers could complete their decision packages earlier which would allow the Mission Area Review panels to convene sooner and have more time to thoroughly review the packages. Although final guidance on the preparation of the decision packages will not have been received by ASD, the Mission Area Review panels would at least have enough information to begin the review process.

Another member stated that a better understanding of how each decision package contributes to the accomplishment of AF goals and objectives would aid in the ranking process. The goals and objectives for many decision packages were stated in terms of what that package was suppose to achieve, not how that package aids in eliminating the deficiencies in the combat mission areas. The decision packages need to be related directly to the goals of the AF.

Many members stated that the tradeoff decisions among the completely different types of programs included in the DWMS mission area could have been improved if the decision packages were written more consistently. The quality and type of information contained in the decision packages varied widely and caused considerable difficulty in the evaluation and tradeoff decision process. Several members recommended that a good quality control system be installed to review the decision packages before the DWMS panel receives them for evaluation. Suver and Brown discuss the problems that can occur when management tries to compare the outputs from non-related decision packages (Suver and Brown, 1977:81). By definition, the DWMS mission area contains many non-related programs.

All of the members stated that they would like to have had some type of feedback on how their ranking compared to the rankings of higher management. Without any information as to how the rankings changed at higher management levels, many members questioned the value of the time spent reviewing and ranking the decision packages. McCandless states that as the last step in the ZBB process top management should provide all lower levels of management the final ranking and any reasons for changes to the initial rankings. In this way, lower management will build up trust in top management and provide complete and unbias information in the future (McCandless, 1978:46-47).

Finally, one member said that there was no reward or recognition for working on the DWMS panel. The POM ranking process was a short two week project that detracted from the panel members' primary jobs with their organizations. They were valuable people from the organization which they represented and their immediate superiors would rather have had them working on their projects than on the POM. The ZBB process, when initiated within the DOD, represented major change to the organization. According to

McCandless, major change in an organization involves three steps. First, the old ideas must be unfrozen. Next, the old ideas must be changed to the new ideas. Finally, the new ideas must be refrozen and supported by the organization's reward system or else the organization's people will have a tendency to revert to the old ideas (McCandless, 1978:47). The ASD reward system as perceived by several panel members did not support the panel members' work.

Summary

This chapter provided a brief description of the DWMS mission area and its programs and summaried ideas concerning the ASD POM process obtained by interviewing the DWMS panel members. Based upon these ideas and concepts discussed in the literature review, a methodology will be developed in the following chapter, which the DWMS panel could use to aid in future evaluation and selection of DWMS programs for the POM.

Chapter 5

DWMS PROJECT EVALUATION/ PROJECT SELECTION MODEL

Once the DWMS Mission Area Review panel has received all the decision package documentation from the program managers, they have to review, evaluate, and rank all those decision packages according to their contribution to AF needs. Since the determination of the contribution to AF needs of any military R&D program requires a very subjective judgement by the evaluator, a process that reduces evaluation inconsistencies and biases would be beneficial to this R&D project selection process. This chapter discusses a scoring model that the DWMS panel can use to evaluate programs and to determine their benefits to the AF. Once the benefits of each decision package and incremental benefit adjustments due to decision package interrelationships have been determined, a 0-1 integer programming model is used to select that project portfolio with maximum benefits to the AF. This chapter includes a demonstration of the 0-1 IP model applied to a hypothetical ZBB problem.

DWMS Benefit Measurement Model

Most of the DWMS panel members stated that a scoring model similar to the one used to evaluate decision packages for the 1982-1986 POM would be satisfactory in evaluating the contributions of each decision package to the goals of the AF. They felt that a more complicated evaluation model would not be appropriate because of the highly subjective nature of the input data. The members did question whether the criteria were appropriate, but given the time constraint, they all felt that the model they used was adequate. One area of improvement recommended by the panel was that an exact definition of each evaluation criteria is required. Several members felt that too much valuable time had been wasted discussing the particulars of each criteria. Even after the discussions, several members were still uncertain as to the exact definition of the criteria and as a result, were not consistent in evaluating all seventy decision packages. The members were not certain whether the last package was evaluated in the same manner as the first package. Also, if all members had a slightly different definition for each criteria, then they were in reality using different criteria to judge the decision packages. A more explicit definition for each evaluation criteria would improve both the internal and external consistency of the evaluation.

As an additional aid, besides a more exact definition, several members mentioned that a list of typical questions that should be asked for each criteria would assist in improving the consistency of the evaluation process. The purpose of the questions would be to stimulate thought rather than being answered specifically. If the questions are thorough, then the panel members can assume that each decision package is evaluated consistently between members and that each member's evaluation of the first and the last decision package is equivalent.

Based on the interviews with the DWMS panel members and the literature review into R&D project evaluation techniques, a scoring model was selected as the appropriate model for the DWMS panel to use to evaluate decision package benefits. This type of model was chosen because of the large ratio of qualitative to quantitative data available, the high uncertainty in the R&D environment, and the heavy reliance on the subjective opinions of the panel members. For many of the programs, it would be either very difficult, not cost effective, or too time consuming to collect the data required to quantify the benefits for either a net present value or internal rate of return calculation. Much of the data, if it could be collected, would be of questionable value because of the degree of uncertainty in that data. The panel members agreed that a scoring model was the most appropriate method for measuring the benefits to the AF of each decision package.

Bemelmans recommends that any scoring model contain no more than five to seven main criteria because it becomes very difficult for management to handle a large number (Bemelmans, 1979:39).

In order to determine the appropriate number and type of evaluation criteria to recommend to the DWMS panel, three sources of information were used. First, a literature review was conducted into R&D project evaluation techniques. Although most of the information pertained to commercial organizations, many of the evaluation criteria and checklist questions could be adapted to military R&D project selection. Cetron specifically discusses military R&D project selection and mentions the following criteria:

1) military utility,
    a) value to warfare
    b) task responsiveness
    c) timeliness
2) technical feasibility, and
3) financial acceptability (Cetron, 1969:57-60).

Cooper, in discussing R&D project evaluation in the federal government, mentions that the feasibility that a project will be successful depends upon the technical risk, the availability of appropriate technical skills and facilities, and the availability of management talents (Cooper, 1978:31).

The second source of information was from interviews conducted with the Mission Area Review panel chairmen. The purpose of the interviews was to discuss the methodology that their panels used to evaluate and rank decision packages within their mission area. One evaluation criteria that was consistently mentioned by the chairmen was that of program timing. Will the end item be available at the appropriate time to counter the threat? A typical evaluation model is that used by the Air-to-Surface Attack Mission Area Review panel which consisted of the following criteria:

1) timeliness

2) risk

   a) high risk

   b) medium risk

   c) low risk

3) contribution

   a) primary--contributes directly to satisfying the need

   b) secondary--contributes directly to satisfying a secondary need

   c) indirect--contributes toward allowing another system to satisfy a need

   d) no contribution (Matzko, 1980).

The last source of information is from the interviews with the DWMS panel members themselves. This is probably the most important source of information because it allows the information obtained from the literature and the other mission area panel chairmen to be tailored to the specific requirements of the DWMS mission area. After reviewing the results from the interviews, especially each individual's definition of the evaluation criteria, it became apparent that five factors were important when evaluating DWMS programs. These factors were as follows: program effectiveness and mission accomplishment, program feasibility, resource acceptability, program timing, and program importance.

The DWMS panel members mentioned that program effectiveness was the most important evaluation criterion when judging a program. It is felt that effectiveness and mission accomplishment are part of a broader criterion, military value or relevance, which attempts to measure the value or usefulness of the program's expected output to the AF. It measures whether the end item can satisfy a projected military need with respect to a future threat. Given that a need exists, what is the contribution of this program in the military environment to the satisfaction of that need? Timeliness is an integral part of military value because in order for a project to be useful, it must provide a new or improved capability in the shortest possible time after its need is recognized. In order for the end item to be effective, it must be available when it is needed to counter the threat. When evaluating military value, the decision maker assumes that the system is feasible and that the resources are available when required. Military value is the potential value from the project, and in order to determine the actual value, project feasibility and resource acceptability must be considered.

Program feasibility measures the risks associated with the program and attempts to measure how realistic the decision package is in the current political, economic, and technical environments. If this decision package is approved, what is the probability that the stated goals will be achieved with the resources now planned? A program must be evaluated with respect to its technical, political, and organizational feasibility. Technical feasibility measures the technical risks associated with the program. It is a measure of the probability that the project will not achieve its goals due to technological bottlenecks. Political feasibility measures the political support for the program. Who is the program's champion? How hard is the champion pushing the program? How high up in the AF did the program originate? The higher up in the AF that the project can gain attention and the more widespread its potential impact, the greater the incentive for its resolution. Organizational feasibility questions the capability of the organization to perform the work. Is the organization technically competent to perform the work? Does the organization have the required engineering, scientific, and managerial talents to successfully complete the project? Finally, implicit in the determination of feasibility is program timing. As an example, if the program is urgently needed and as a result the program's schedule is compressed, then the technical risks associated with the program could be increased especially if advanced technology is required.

Resource acceptability attempts to measure the reasonableness of the resource assumptions. When evaluating project resource requirements, not only must the availability of the required resources be determined but also that level must be acceptable to the organization. For example, the high percentage of available resources consumed by one decision package may not be acceptable to the DWMS mission area panel because it would starve too many of the other programs. If this decision package is approved, what is the probability that the resources planned will be provided considering the competition for resources? Resource timing is very important when determining the acceptability of the resource requirements to the DWMS panel. Will the resources be available when required to successfully complete this program? Are the future funding requirements realistic, and if questionable, what is the probability of a cost overrun? Resource acceptability can only be accurately determined by evaluating the resource requirements over the complete time period in the FYDP.

Just determining that a project can fulfill a need is not justification for allocating scarce AF resources to the fulfillment of that need. The additional information required is how important satisfying that need is to the AF. What is the importance of the AF need being addressed with respect to the AF's strategic plan? The AF cannot afford to satisfy all of its needs and therefore, has developed a priority list of needs which provides an indication of the importance that the AF places on different programs. A program may satisfy a large deficiency, but if the AF does not place much importance on the elimination of that deficiency, then the program should not be funded.

Discussions about a proposed model with the DWMS panel chairman in order to help verify that model suggested that the determination of a program's importance was too subjective and should be handled by a group effort (Weber, 1980b). He proposed that each panel member evaluate a decision package using the following model:

$$\begin{bmatrix}\text{Individual} \\ \text{Score}\end{bmatrix} = \begin{bmatrix}\text{Military Value} \\ \text{Score}\end{bmatrix} + \begin{bmatrix}\text{Feasibility} \\ \text{Score}\end{bmatrix} + \begin{bmatrix}\text{Resource Accept-} \\ \text{ability Score}\end{bmatrix}$$

Once the panel reconvenes, a group importance score for each decision package will be determined. The total benefit score, which will be used as the objective function coefficient in a 0-1 IP selection model, will be the sum of all the individual scores for that decision package times the group importance score for that decision package. The justification for multiplying the importance score is that if a decision package is rated low in importance, then the total score for that decision package should also be low. The scoring model is shown in Appendix A.

After each decision package has been individually reviewed and evaluated, two more evaluations have to be performed. First, the decision packages are reviewed to determine if there are any compulsory or alternate compulsory packages. If there are any, those packages have to be flagged so that the appropriate constraints can be formulated. The second review is to determine if there are any interdependencies between programs. Program interdependencies will be formulated in the form of a self-interaction matrix which will be discussed in the next section and will be explicitly included in the selection model.

1	0	1	0	1	1	1	A_8
1	1	0	1	0	1	A_7	
0	1	1	0	1	A_6		
1	0	1	1	A_5			
0	0	0	A_4				
0	0	A_3					
1	A_2						
A_1							

Figure 7: Binary Interaction Matrix

Self-Interaction Matrix

To assist the DWMS panel in formulating the interrelationships between programs but not within programs, an adaptation of the self-interaction matrix, as discussed by Sage, will be used. The self-interaction matrix is a convenient format for presenting the interrelationships between any two programs. In a binary interaction matrix, Figure 7, a one indicates that a direct interaction between programs occurs while a zero indicates no direct interaction. If there are n elements, there are $\frac{n(n-1)}{2}$ entries to be made in the self-interaction matrix (Sage, 1977:13-24).

In order to adapt the self-interaction concept for use by the DWMS panel, several changes have to be made. First, if two programs interact, either positively or negatively, the magnitude of that interaction, expressed as an adjustment to the organization's benefits, is entered in the appropriate matrix position. Secondly, the self-interaction matrix represents interrelationships between programs but not within programs. Therefore, the matrix elements which correspond to an interaction between decision packages for the same program represent non-feasible interactions. Because of this last requirement, the total number of possible interactions is given by the following formula:

$$\begin{bmatrix}\text{Total Possible} \\ \text{Interactions}\end{bmatrix} = \frac{\sum_{i=1}^{n} m_i \left[\sum_{i=1}^{n} m_i - 1\right]}{2} - \left[\sum_{i=1}^{n} \sum_{j=1}^{m_i - 1} j\right]$$

The first term of the formula is an adaptation of the formula given by Sage (Sage, 1977:13) to the case of ZBB where there are m_i decision packages in each of i programs. The second term is an adjustment

3	2	-1	-4	-	-	-	DP_{24}
3	2	1	-3	-	-	DP_{23}	
2	1	0	-2	-	DP_{22}		
1	0	0	-1	DP_{21}			
-	-	-	DP_{14}				
-	-	DP_{13}					
-	DP_{12}						
DP_{11}							

Two Programs, Each Having Four Decision Packages

0	0	-1	-2	-3	-3	-	-	DP_{33}
0	0	0	-1	-2	-2	-	DP_{32}	
0	0	0	-1	-1	-2	DP_{31}		
2	3	-	-	-	DP_{24}			
1	2	-	-	DP_{23}				
0	1	-	DP_{22}					
0	0	DP_{21}						
-	DP_{12}							
DP_{11}								

Three Programs: Program One Has Two Decision Packages

Program Two Has Four Decision Packages

Program Three Has Three Decision Packages

Figure 8: Self-Interaction Matrix in ZBB Format

to disregard those elements corresponding to decision packages for the same program interacting with each other. Figure 8 illustrates the self-interaction matrix adapted to ZBB form.

0-1 Integer Programming Model Development

Once the DWMS panel has evaluated each decision package and determined its benefit, that benefit can be used as the coefficient of the objective function in a 0-1 integer programming model. A 0-1 approach has been selected because this approach allows for the "go-no go" type of decision required in ZBB. Either all or none of a particular decision package has to be selected. The manner in which decision packages are defined and constructed does not allow for a fractional part of a decision package to be selected. A mathematical programming approach to the R&D project selection decision is preferred to either scoring models or economic models because:

1) it can be formulated to include multiple resource constraints over several time periods;

2) it can be formulated to include compulsory projects and alternate project versions; and

3) it selects a portfolio which maximizes total benefits to the organization.

Bell's formulation (Gear _et al._, 1971:66-68) of the R&D project selection problem has been adapted to the ZBB decision package selection problem. Improvements to Bell's model, which allow for project interdependencies, have been formulated. Resource constraints which may apply to the DWMS panel are multi-year budget limits, manpower limitations, and facilities contraints. Additional possible constraints are the following: a compulsory project with a lower bounded decision package, alternate compulsory projects with lower bounded decision packages, mutually dependent projects, and mutually exclusive project decision packages.

When the DWMS panel members were evaluating each decision package, they tried to consider the multi-year funding requirements of that decision package and the impact that those requirements would have on future project portfolios. Looking only at the first year of the FYDP, a particular program could have a low funding requirement and seem attractive to the AF but the funding levels in the following four years could require a large portion of the estimated budget. Looking at the complete FYDP, the project would be very unattractive and should not be included in the first year's recommended portfolio.

Two DWMS projects may have either a synergistic or cannibalistic effect on each other, and their summed benefits would not reflect their true contributions to the DWMS mission area. In order to include project interactions in the 0-1 IP model, the objective function is expanded to include nonlinear terms. These nonlinear terms are of the form, $x_{1j}x_{2j}$, and signify that the benefit contribution to the organization for particular combinations of any two programs is not additive. The coefficient of the nonlinear term represents the adjustment to the objective function required by selecting a particular combination of projects for the final portfolio and is obtained from the self-interaction matrix.

The solution method depends upon the approach taken to formulate the interaction problem. If the nonlinear terms' coefficients represent a change in benefits, then an approach to solving nonlinear 0-1 programming problems as suggested by McMillan is adapted to the ZBB problem (McMillan, 1975:499-501). If the coefficients represent the total benefits to the organization, then the problem can be formulated and solved by creating a new project which represents the combination of the two interacting projects. Both approaches will be demonstrated by simple examples.

Zero-Base Budgeting 0-1 Integer Programming Model

The final R&D project selection model suggested for use by the DWMS Mission Area Review panel is of the form:

$$\text{Maximize:} \quad z = \sum_{i=1}^{n} \sum_{j=1}^{m_i} b_{ij} x_{ij} + \sum_{s=1}^{u} b_s I_s$$

Subject to:

1. Resource Constraints

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} a_{ijkp} x_{ij} \leq A_{kp} \qquad k = 1, 2, \ldots, N \quad p = 1, 2, \ldots, P$$

2. Mutually Exclusive Decision Packages for the Same Program

$$\sum_{j=1}^{m_i} x_{ij} \leq 1 \qquad i = 1, 2, \ldots, n$$

3. Mutually Dependent Decision Packages for Separate Programs

   a. One-Way Dependency: If at least decision package x_{1r_1} is selected, then at least decision package x_{4r_4} has to be selected.

$$\sum_{j=r_1}^{m_1} x_{1j} - \sum_{j=r_4}^{m_4} x_{4j} \leq 0$$

   b. Two-Way Dependency: If either at least decision package x_{1r_1} or at least decision package x_{4r_4} is selected, then at least x_{1r_1} and at least x_{4r_4} have to be selected.

$$\sum_{j=r_1}^{m_1} x_{1j} - \sum_{j=r_4}^{m_4} x_{4j} = 0$$

4. Compulsory Project with Lower Bounded Decision Package

$$\sum_{j=r_i}^{m_i} x_{ij} = 1$$

5. Alternate Compulsory Projects with Lower Bounded Decision Packages

$$\sum_{j=r_1}^{m_1} x_{1j} + \sum_{j=r_4}^{m_4} x_{4j} \geqq 1$$

6. Project Interaction Constraints

$$x_{ab} + x_{cd} - I_s \leqq 1$$

$$-x_{ab} - x_{cd} + 2I_s \leqq 0$$

where x_{ab} and x_{cd} are two projects, a and c, whose decision packages, b and d, interact and $a \neq c$.

7. x_{ij} = 1 if decision package j of project i is selected

x_{ij} = 0 if decision package j of project i is not selected

$i = 1, 2, \ldots, n$

$j = 1, 2, \ldots, m_i$

8. $$I_s = x_{ab}\,x_{cd} \quad \begin{cases} = 1 & \text{if } x_{ab} \text{ and } x_{cd} \text{ are selected} \\ = 0 & \text{if } x_{ab} \text{ and } x_{cd} \text{ are not selected} \end{cases}$$

$$s = 1, 2, \ldots, u$$

Where:

b_{ij} is the benefit of decision package j of project i

b_s is the incremental benefit change caused by selecting both x_{ab} and x_{cd}

u is the total number of decision package inter-relationships

m_i is the number of decision packages for project i

n is the number of projects

N is the number of resource categories considered

P is the number of periods in the planning horizon

a_{ijkp} is the amount of resource type k required for decision package j of project i in time period p

A_{kp} is the overall availability of resource type k in time period p

r_i is the lower bounded decision package of project i

I_s is an interaction term representing the selection of both x_{ab} and x_{cd}

Before the application of the model is demonstrated, a discussion follows of each constraint and how the self-interaction matrix concept can be used to determine the interaction coefficient for the objective function.

Resource Constraints

The funding requirements for each decision package submitted to the DWMS panel are for a period of five years. Rather than considering only the project costs for the first year, all five years can be considered. In order to aid in establishing the multi-year cost constraints, the cost coefficients for each DP can be organized in a tableau such as illustrated in Figure 9. The projected yearly budget can be estimated as the sum of the decision package three funding requirements for all approved programs for each year, or for the first year only, the budget figure as directed by AFSC. Mathematically, this can be expressed as follows:

$$A_{1p} = \sum_{i=1}^{n} a_{i31p} \qquad p = 1,2,3,4,5$$

The budget is resource type 1.

Manpower, facilities, or any other constraint that the DWMS panel feels appropriate can be formulated in a similar manner. However, during the interviews with the DWMS panel chairman and members, they indicated that manpower and facilities were not a constraint in last year's decision package evaluation and ranking process.

Mutually Exclusive Decision Packages for the Same Program

The mutually exclusive decision package constraint does not

Program	Decision Package	Year 1	Year 2	Year 3	Year 4	Year 5
		Resource Type k Required Per Year				
1	1	a_{11k1}	a_{11k2}	a_{11k3}	a_{11k4}	a_{11k5}
	2	a_{12k1}				.
	3	.				.
	4	.				.
2	1	a_{21k1}				.
	2					
	3					
	4					
.						
.						
.						
.						
n	1	.				.
	2	.				.
	3	.				.
	4	a_{n4k1}	.	.	.	a_{n4k5}
Resource Type k Available		A_{k1}	A_{k2}	A_{k3}	A_{k4}	A_{k5}

Figure 9: Multi-Year Decision Package Resource Requirement

allow two decision packages for the same program element to be included in the final portfolio. One constraint is required for each program included in the DWMS mission area. If there are two programs under consideration and program one has four decision packages and program two has five decision packages, then two constraints are required.

$$\sum_{j=1}^{4} x_{1j} \leq 1 \text{ or } x_{11} + x_{12} + x_{13} + x_{14} \leq 1$$

and

$$\sum_{j=1}^{5} x_{2j} \leq 1 \text{ or } x_{21} + x_{22} + x_{23} + x_{24} + x_{25} \leq 1$$

Mutually Dependent Decision Packages for Separate Programs

The one-way dependency occurs if, before one program's decision package can be funded, another program's decision package has to be funded. Possibly decision package two of program one is dependent upon results obtained from a specific project which is not included in program two until decision package three is selected. In this particular case, it should not be possible to select program one, decision package two or higher unless at least decision package three of program two is selected. Mathematically,

$$\sum_{j=2}^{m_1} x_{1j} - \sum_{j=3}^{m_2} x_{2j} \leq 0$$

or

$$x_{12} + x_{13} + \ldots + x_{1m_1} - x_{23} - \ldots - x_{2m_2} \leq 0.$$

Two-way dependency is similar to one-way dependency except the reverse is also true. If at least a certain decision package for one program is chosen, at least a certain decision package for another program has to be selected and visa versa. This could occur where a high cost piece of equipment is required by two programs and the selection of only one program does not justify the cost. Mathematically,

$$\sum_{j=2}^{m_1} x_{1j} - \sum_{j=3}^{m_2} x_{2j} = 0$$

or

$$x_{12} + \ldots + x_{1m_1} - x_{23} - \ldots - x_{2m_2} = 0.$$

Compulsory Project with Lower Bounded Decision Package

This is the case where at least a certain decision package for a program is required to be funded. Perhaps higher management has directed that at least a certain DP has to be funded, or perhaps there exists a "letter of agreement" which states that the AF will provide at least a minimum level of funds for a joint project. In last year's DWMS mission area, ASD overhead, ASD telecommunications, and 4950th Test Wing overhead were evaluated as compulsory projects bounded by DP3. At least DP3 had to be selected, but if the DWMS panel had determined that DP4 was more valuable to the AF than other possible programs, then DP4 instead of DP3 could be included in the final portfolio. Mathematically,

$$\sum_{j=3}^{m_1} x_{1j} = 1$$

or

$$x_{13} + \ldots + x_{1m_1} = 1.$$

Alternate Compulsory Projects with Lower Bounded Decision Packages

This is the case where higher management has said that either at least decision package two of program one or at least decision package two of program two has to be funded but it does not matter which one. The 0-1 IP model is allowed to select the decision package which contributes the most to the project portfolio so as to maximize the benefits to the organization. Mathematically,

$$\sum_{j=2}^{m_1} x_{1j} + \sum_{j=2}^{m_2} x_{2j} \geq 1$$

or

$$x_{12} + \ldots + x_{1m_1} + x_{22} + \ldots + x_{2m_1} \geq 1.$$

Note, that if x_{22} is selected first, there is no longer a constraint on x_{1j} so that x_{11} can be included in the final portfolio.

Project Interactions

After the DWMS panel has completed the self-interaction matrix for all programs under consideration, the information contained in the matrix can be used to obtain the interaction terms of the objective function. The procedure is a two step process. First, for every nonzero element in the interaction matrix, which corresponds to an interaction between project "a" decision package "b" and project "c" decision package "d," a new variable, I_s, is created. Second, the value of that nonzero element, which represents the incremental benefit change caused by selecting project "a" decision package "b" and project "c" decision package "d," is the coefficient, b_s, for use in the objective function.

Since all variables are 0-1 and I_s can only equal one if both x_{ab} and x_{cd} are equal to one because $I_s = x_{ab}x_{cd}$, the following two constraints are required for each interaction:

$$x_{ab} + x_{cd} - I_s \leq 1 \qquad (1)$$

and

$$- x_{ab} - x_{cd} + 2I_s \leq 0 \qquad (2)$$

To demonstrate that these two constraints cause I_s to have the appropriate values consider the following:

1. When $x_{ab} = x_{cd} = 0$, constraint 1 does not constrain I_s, but constraint 2 causes $I_s = 0$.

2. When $x_{ab} = 0$, $x_{cd} = 1$ or $x_{ab} = 1$, $x_{cd} = 0$, constraint 1 and constraint 2 cause $I_s = 0$.

3. Finally, when $x_{ab} = x_{cd} = 1$, constraint 1 becomes

$$1 + 1 - I_s \leq 1 \quad \text{or} \quad I_s \geq 1$$

and constraint 2 becomes

$$- 1 - 1 + 2I_s \leqq 0 \qquad \text{or } I_s \leqq 1$$

and both can only be satisfied if $I_s = 1$ (McMillan, 1975:500).

Example 1--R&D Project Selection with Project Interrelationships--Method 1

A short example will demonstrate how project interrelationships can be included in the R&D project selection model when the project interrelationships are expressed as incremental benefit changes. Assume that there are two projects each having two decision packages under consideration. The funding requirements for each decision package and all other appropriate decision package information has been submitted to a panel of experts which has to evaluate and select the best project portfolio within given constraints. The panel proceeds as follows:

1. Evaluate the benefits of the separate decision packages to the organization.

Program	Decision Package	Cost	Benefit
1	1	10	10
	2	20	15
2	1	8	6
	2	19	14

2. Construct the self-interaction matrix and eliminate non-feasible interactions.

		--	22
		21	
--	12		
11			

3. For all feasible interactions, evaluate whether selecting the corresponding pair of decision packages has an additional impact on the benefits to the organization. For no impact, enter zero. For any impact, enter the magnitude of that impact. For this example, all decision packages interact. Note that x_{11} and x_{21} have a 2 unit cannibalistic effect on the organization's benefits. The other interactions are shown below.

-3	1	--	22
-2	3	21	
--	12		
11			

4. For each element that has a non-zero value, create a new variable I_s. A new self-interaction matrix can be used to aid in the necessary bookkeeping.

I_2	I_4	--	22
I_1	I_3	21	
--	12		
11			

The variable I_1 corresponds to the selection of both x_{11} and x_{21}.

5. Use this information plus a budget constraint of 30 to formulate a 0-1 IP model to solve this problem.

$$\text{Maximize:} \quad z = 10x_{11} + 15x_{12} + 6x_{21} + 14x_{22} - 2I_1 - 3I_2 + 3I_3 + I_4$$

Subject to:

(1) Resource Constraint

$$10x_{11} + 20x_{12} + 8x_{21} + 19x_{22} \leq 30$$

(2) Mutually Exclusive Decision Packages

$$x_{11} + x_{12} \leq 1$$

$$x_{21} + x_{22} \leq 1$$

(3) Project Interaction Constraints

$$x_{11} + x_{21} - I_1 \leq 1$$

$$- x_{11} - x_{21} + 2I_1 \leq 0$$

$$x_{11} + x_{22} - I_2 \leq 1$$

$$- x_{11} - x_{22} + 2I_2 \leq 0$$

$$x_{12} + x_{21} - I_3 \leq 1$$

$$- x_{12} - x_{21} + 2I_3 \leq 0$$

$$x_{12} + x_{22} - I_4 \leq 1$$

$$- x_{11} - x_{22} + 2I_4 \leq 0$$

(4) 0-1 Constraints

All variables = 0, 1

The solution to this problem is to select projects x_{11} and x_{21}. The cost to the organization is 28, and the selected portfolio provides the maximum possible benefits which is 24.

Example 2--R&D Project Selection with Project Interrelationships--Method 2

An alternate 0-1 IP formulation can be used when the total benefit for selecting a particular project combination is known. This is the case where it is easier to determine the total benefits for selecting two projects rather than determining the incremental change in benefits. The previous example will be used to demonstrate this procedure.

1. Evaluate the benefits of the separate decision packages to the organization.

Program	Decision Package	Cost	Benefit
1	1	10	10
	2	20	15
2	1	8	6
	2	19	14

2. Construct the self-interaction matrix and eliminate non-feasible interactions.

		--	22
		21	
--	12		
11			

3. For all feasible interactions, determine the total benefits to the organization for selecting the corresponding pair of decision packages. Compare the benefits with interactions to the summed total of benefits from the two individual decision packages. If there is no difference, enter zero in that element of the matrix. If a difference exists, enter the interaction benefits.

21	30	--	22
14	24	21	
--	12		
11			

4. For each element that has a non-zero value, create a new variable I_s.

I_2	I_4	--	22
I_1	I_3	21	
--	12		
11			

The selection of I_1 in the final solution implies that projects x_{11} and x_{21} are selected.

5. For each I_s, determine the resource level required for this particular decision package combination. Again, the concept of a self-interaction matrix will be used. Under the assumption of no overlap in project resource utilization, the resource requirement for I_s would be the summed total of the resource requirements for x_{ab} and x_{cd}. If there was an interdependency due to overlap in project resource requirements, then the actual resource requirement would be entered into the matrix. In this example, there is no interdependency in funds required so the funds required by I_s is the summed total of funds required for x_{ab} and x_{cd}.

29	39	--	22
18	28	21	
--	12		
11			

6. Formulate a 0-1 IP model with a budget constraint of 30.

$$\text{Maximize:} \quad z = 10x_{11} + 15x_{12} + 6x_{21} + 14x_{22} + 14I_1 + 21I_2 + 24I_3 + 30I_4$$

Subject to:

(1) Resource Constraint

$$10x_{11} + 20x_{12} + 8x_{21} + 19x_{22}$$

$$+ 18I_1 + 29I_2 + 28I_3 + 39I_4 \leq 30$$

(2) Mutually Exclusive Decision Packages

$$x_{11} + x_{12} \leq 1$$

$$x_{21} + x_{22} \leq 1$$

(3) Project Interaction Constraints

Under this approach, project interaction constraints are changed to the following form,

$$x_{ab} + x_{cd} + I_s \leq 1,$$

for each I_s.

$$x_{11} + x_{21} + I_1 \leq 1$$

$$x_{11} + x_{22} + I_2 \leq 1$$

$$x_{12} + x_{21} + I_3 \leq 1$$

$$x_{12} + x_{22} + I_4 \leq 1$$

(4) 0-1 Constraints

All variables = 0, 1

Solving this problem yields the selection of I_3 which implies the selection of projects x_{12} and x_{21} because $I_3 = x_{12}\, x_{21}$. Total benefits are 24 for a cost of 28.

The first method of incorporating decision package interdependencies is suggested for use by the DWMS panel for two reasons.

First, the DWMS panel believed that the fiscal constraint was the only constraint pertinent to their selection process. Since the panel had no authority to change any funding requirements for any decision packages, advantage could not be taken of the possibility that funding two programs together required less funds than funding each program separately. Secondly, due to the large number of programs and decision packages, it would be easier to evaluate the benefits of each decision package separately and then evaluate the change in benefits caused by funding particular combinations of decision packages.

Next, a more complicated example with ten programs and thirty-seven decision packages will demonstrate the detailed use of the model. The final output will be a complete ranking of decision packages for submission to the next higher level of management in the ZBB process.

Example 3--Multi-Program R&D Project Selection

The example developed to demonstrate the full use of the model contains ten programs and thirty-seven decision packages. It is assumed that the mission area review panel has already met and determined the benefits of each decision package to the AF. The results from the decision package evaluations and the multi-year funding requirements for each decision package are shown in Table I.

AFSC has provided the panel with a budget amount of 35 for the first year of the five year funding requirements. For all other years, two through five, the decision package threes for all approved programs are summed and represent the projected budget levels for the appropriate year. Two programs, two and five, are new starts, and only decision packages one and four for each are submitted. Program nine represents a program which is completed at the end of year three and therefore, requires no funds in years four and five. Program two is a program whose costs are low in the first year but rapidly escalate in the next four years. Program five represents a new start which requires a large percentage of the total yearly funds available. Finally, program ten represents a program which provides high benefits to the organization but requires a relatively high investment in order to be selected.

The procedures required to formulate the problem are similar to those in example one.

1. Evaluate the benefits of the separate decision packages to the organization using the scoring model presented in the beginning of this chapter. Calculate the benefit-cost ratio for each decision package based upon the first year package cost. The results of this evaluation are shown in Table I.

2. Construct the self-interaction matrix and eliminate nonfeasible interactions.

TABLE I

PROGRAM INFORMATION FOR EXAMPLE 3

Program	Decision Package	Funding Requirements by Year 1	2	3	4	5	Bene-fits	Benefit-Cost Ratio
1	1	.7	.8	.9	1.1	1.2	4	5.71
	2	1.4	1.5	1.6	1.8	1.9	28	20.0
	3	2.7	2.8	3.0	3.2	3.4	34	12.59
	4	3.8	3.9	4.0	4.2	4.3	45	11.84
	5	5.1	4.2	4.3	4.3	4.3	47	9.22
2	1	1.6	3.6	4.2	4.8	5.0	30	18.75
	4	3.1	4.0	4.3	4.9	5.2	39	12.58
3	1	1.3	1.4	1.6	1.7	1.9	30	23.08
	2	2.6	2.9	3.1	3.5	3.8	42	16.15
	3	5.2	5.7	6.3	6.9	7.6	50	9.62
	4	6.1	6.7	7.4	8.1	8.9	51	8.36
4	1	.6	.7	.8	1.0	1.1	12	20.0
	2	1.1	1.2	1.3	1.5	1.7	22	20.0
	3	2.2	2.4	2.2	2.9	3.2	29	13.18
	4	3.4	3.6	3.8	4.0	4.1	30	8.82
5	1	10.2	10.8	11.5	12.1	12.9	11	1.08
	4	12.4	12.9	13.4	13.9	14.2	15	1.21
6	1	1.1	1.2	1.3	1.3	.8	19	17.27
	2	2.1	2.3	2.4	2.3	1.8	25	11.90
	3	4.2	4.5	4.9	4.0	2.6	28	6.67
	4	5.1	5.4	5.7	4.9	2.9	30	5.88
7	1	.9	1.0	1.1	1.4	1.6	13	14.44
	2	1.9	2.1	2.3	2.4	2.6	18	20.0
	3	3.7	4.1	4.3	4.6	4.9	26	7.03
	4	4.8	5.3	5.6	6.0	6.3	28	5.83

TABLE I (Cont.)

Program	Decision Package	Funding Requirements by Year 1	2	3	4	5	Bene-fits	Benefit-Cost Ratio
8	1	.5	.7	.8	.9	1.2	16	32.0
	2	1.1	1.2	1.3	1.5	1.7	24	21.82
	3	2.2	2.3	2.3	2.4	2.5	29	13.18
	4	3.9	3.9	4.0	4.0	4.1	30	7.69
9	1	1.3	1.0	.7	0	0	31	23.85
	2	2.1	1.8	.8	0	0	36	17.14
	3	3.6	3.4	1.2	0	0	41	11.39
	4	4.9	4.2	2.6	0	0	44	8.98
10	1	6.4	6.7	7.1	7.4	7.8	27	4.22
	2	7.9	8.2	8.5	8.8	8.9	40	5.06
	3	8.8	9.1	9.3	9.6	9.9	47	5.34
	4	10.1	10.2	10.3	10.1	10.0	49	4.85
Estimated Funds Available	$\sum_{i=1}^{n} a_{i3\ell p}$	35 (AFSC Figure)	34.3	34.0	33.6	34.1		

p=2,3,4,5

For a large problem with many possible interactions, it would be easier to construct the self-interaction matrix only for those projects that interact. Figure 10 shows a portion of the total self-interaction matrix containing programs one, two, four, and eight.

3. For all feasible interactions, evaluate whether selecting the corresponding pair of decision packages has an additional impact on the benefits to the organization.

For this example, it is assumed that programs are not interdependent; therefore, all the elements in the self-interaction matrix are zero. Selecting two projects does not have either a synergistic or cannibalistic effect on the total benefits from the project portfolio.

4. Flag compulsory decision packages. At least decision package 33 must be chosen. Either at least decision package 42 or at least decision package 62 must be chosen.

5. The problem is now formulated using the 0-1 IP model. The computer formulation is shown in Appendix B.

The resulting 0-1 IP problem was solved by the use of Multi Purpose Optimization System (MPOS) on a Cyber 74 computer at ASD. The advantages of MPOS are that the language allows the user to state the problem in English and algebraic notation and the efficiency of the MPOS 0-1 algorithm (Cohen and Stein, 1978:1).

In order to obtain the rank order of decision packages as

											-	-	-	84
											-	-	83	
											-	82		
											81			
							-	-	-	44				
							-	-	43					
							-	42						
							41							
					-	24								
					21									
-	-	-	-	15										
-	-	-	14											
-	-	13												
-	12													
11														

Figure 10: Portion of Total Self-Interaction Matrix

specified by ZBB, the program was first run looking only at the funding requirements for the first year. In this case, the budget constraint of 35, which was provided by AFSC, was used and the resulting portfolio is shown in Table II. Next, the problem was run considering the funding requirements for all five years in the FYDP. Again, the resulting portfolio is shown in Table II. The multi-year nature of the problem will change the portfolio if any year's budget constraint other than the first year's constraint becomes binding. In this example, the portfolio did change with decision package 15 being selected in place of decision packages 73 and 93. It would be a management decision which portfolio to select.

In order to determine how sensitive the project portfolio was to changes in the funding level and to aid in the ranking process, the program was run considering only the first year and varying the budget constraint from a low value of 10 to a high value of 55. All programs would be selected if 58.8 funds were available. The results for an incremental change of five are shown in Table II and are the optimal portfolio at that funding level. Smaller incremental changes could be performed around the budget figure if additional analysis was necessary.

One of the most difficult tasks in ZBB is the actual ranking of decision packages which is the ultimate end result of the process. Cheek claims that what is required is an efficient method which

TABLE II

DECISION PACKAGE PORTFOLIOS

Resource Constraint	10	15	20	25	30	35 Single Year	35 Multi-Year	40	45	50	55
Decision Package Portfolios	21 33 42 81 91	12 21 33 43 61 71 82 91	14 21 33 43 62 72 82 92	14 21 33 42 61 71 82 91 103	14 21 33 43 62 72 83 92 103	14 24 33 43 62 73 83 93 103	15 24 33 43 62 72 83 92 103	15 24 33 43 62 74 83 94 104	15 24 34 44 64 74 83 94 104	14 24 33 43 54 62 73 83 94 104	14 24 33 44 54 64 74 83 94 104
Total Benefits	149	224	257	281	309	337	320	340	347	351	359
Total Cost	9.7	14.8	20	24.9	29.9	34.7	Year 1-32.7 2-33.9 3-30.4 4-31.4 5-32.8	39.7	44.8	49.7	55

focuses and directs the organization's resources towards those programs which provide the most promise of achieving the preagreed needs of the organization (Cheek, 1977:54). The 1982-1986 POM guidance provided little detail on the ranking procedures to be used, leaving the decision up to each Mission Area Review panel. The only guidance was that the ranking should normally be accomplished in conjunction with mission area analysis and the AF Planning Guide (ASD/ACB, 1979:57).

The following procedure will be suggested for use by the DWMS panel in ranking decision packages and will be demonstrated by this example.

1. All compulsory projects and the alternate compulsory projects that have been selected are ranked at the top of the list of decision packages. For this example, x_{33} is a compulsory package, and x_{42} is the first alternate compulsory project to be selected. Both appear at the top of the ranking list.

2. Sensitivity analysis is performed on the budget constraint around the estimated budget figure for the first year of the FYDP. The range is predetermined by the DWMS panel and is sufficient to clearly differentiate between those projects which will definitely be selected, marginal projects, and those which will not definitely be selected. The budget constraint will be incremented around the estimated budget figure in order to determine which of the marginal

programs should be selected and the order of selection. A tradeoff decision has to be made when determining the appropriate increment size between the number of computer runs required and the amount of detail desired about the selection order for marginal programs. If the budget figure for the first year of the FYDP for the DWMS mission area is 380, a suggestion would be to increment the budget constraint from 340 to 420 in increments of 10.

For this example, the budget for the first year is 35. A reasonable range over which to increment the budget constraint is from 25 to 45 in increments of 5. Table III illustrates the portfolio for a budget constraint of 25 and the additional decision packages that are selected as the budget constraint is increased.

3. Rank all decision packages that are included in the portfolio for the lowest budget constraint according to their benefit-cost ratio. In this example, all decision packages that are included in the portfolio for a resource level of 25 except for compulsory projects are ranked according to their benefit-cost ratio.

4. As additional decision packages are added at higher resource levels, order the added decision packages according to their benefit-cost ratio without changing previously ranked decision packages. For this example, when the resource level is increased to 30 from 25, decision packages 72, 92, 43, 62, and 83 are now included in the desired portfolio. These additional decision packages

are ranked according to their benefit-cost ratio. The ranking for a resource level of 25 is not changed.

5. Repeat step four until the upper limit of the predetermined resource range has been obtained.

6. All remaining decision packages are ranked according to their benefit-cost ratios.

For this example, the final decision package ranking is shown in Table III. If available funds are reduced below 35, DP73 would be the first to be eliminated. DP15 would be the first decision package added to the portfolio if the funds available are increased above 35.

Summary

This chapter presented a scoring model that the DWMS panel can use to evaluate the benefits of each decision package and a project selection model which selects the decision package portfolio with the maximum benefits to the AF. The next chapter presents the conclusions drawn from this study and the final recommendations to the DWMS panel for improving the 1983-1987 POM process.

TABLE III

FINAL DECISION PACKAGE RANKING

Decision Package	Resource Levels	Decision Package	Resource Levels
33		24	
42		93	
81		73	35
91		15	
82		94	
12		74	
21		104	40
61		44	
71		34	
13		63	
14		64	45
103	25	84	
72		51	
92		54	
43			
62			
83	30		

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions drawn from this research effort, and based upon those conclusions, recommendations to the DWMS Mission Area Review panel for improving the 1983-1987 POM process. The recommendations will be integrated with improvements that already have been suggested by the corporate management at ASD.

Several key conclusions drawn from this study are as follows:

1) the decision package information collected from the program managers is not consistently prepared;

2) it is very difficult for the DWMS panel members to evaluate the decision packages with respect to AF long-range goals because the objectives of each decision package and the goals of the AF are not explicitly stated;

3) the internal and external consistency of the DWMS decision package evaluation process needs to be improved so that all panel members can evaluate each decision package equivalently;

4) an appropriate selection model, which allows for multiple constraints and project interdependencies, needs to be developed; and

5) finally, a timetable of events needs to be developed in order to permit a thorough evaluation of all DWMS decision packages to be performed.

In order to increase the consistency of the decision packages and to tie those decision packages to AF long-range goals, ASD/AC (Comptroller) and ASD corporate management should provide further preparation guidance to the program managers and the Mission Area Review panel members. This guidance could be in the form of either a briefing or detailed letter which would discuss the following:

1) the purpose and philosophy of the POM ranking process,

2) the type of information which should be included in the decision packages,

3) the importance of providing accurate estimates,

4) how vital it is to the AF that the decision package goals be related to, as clearly as possible, AF goals, and

5) a clear definition of exactly what those AF goals are.

If well prepared decision packages are received by the Mission Area Review panels, especially the DWMS panel, the process of selecting the most appropriate decision packages could be enhanced considerably. It would be less probable that an inappropriate decision package would be selected.

To further increase the consistency of the decision packages, ASD/AC should review the packages before they are sent to the

Mission Area Review panels. If a package did not meet the quality control standards, then it would be sent back to be reworked by the program manager.

In order to improve the consistency of evaluating decision packages by the DWMS panel, it is recommended that the scoring model developed in this thesis be used to measure the benefits to the AF of each decision package. Once the benefits have been determined, the 0-1 integer programming model should be used to develop the decision package ranking for the POM.

In order to aid the DWMS panel chairmen and ASD/XR in scheduling events for the 1983-1987 POM evaluation process, the following timetable has been developed. This timetable incorporates improvements to the ASD POM process suggested by ASD's corporate management (ASD/AV, 1980:15-16) and proposed by this research effort. At the beginning of October, the Mission Area Review panels members will be selected and along with the program managers attend a briefing conducted by ASD/AC and ASD corporate management. This briefing will cover ASD's strategic plan, AF goals, the philosophy of ZBB, and decision package preparation. After this briefing, the program managers will have two weeks to prepare all decision packages and submit them back to ASD/AC for quality control. During the third week of October, ASD/AC will review all the decision packages to determine if they are consistently prepared.

Those decision packages that do not meet the quality control standards will be returned to the program managers for rework. These three weeks will allow each Mission Area Review panel to review the most current BES which was submitted in September, the Air Force Planning Guide, and the "P" series documents to determine the AF needs in each mission area. Also, during these three weeks, each panel can discuss and determine the decision package evaluation and selection strategy that will be used to rank and select decision packages. This research has suggested and demonstrated one such strategy.

Around the last of October, the Mission Area Review panels receive their appropriate decision packages and the individual review process begins. Following the Vanguard briefings in November, each panel will initially rank their decision packages based on mission requirements. The scoring and decision package selection models discussed in this thesis have been developed for use by the DWMS Mission Area Review panel. The results from these initial rankings are presented to the Program Review Group for review in late November. When the final fiscal guidance is received in early December, the rankings will be adjusted as necessary, and the results presented to the Decision Review Group for review and approval.

Areas for further research include the following:

1) an evaluation of the cost effectiveness of starting the

decision package rankings at the Product Division level rather than starting at either AFSC or the Air Staff;

2) an analysis of the different methods that firms use to evaluate R&D projects;

3) expand the presented 0-1 integer programming model to include multiple criteria; and

4) finally, an investigation into the best method to rank decision packages for the POM when using the 0-1 integer programming R&D project selection model presented in this thesis.

APPENDICES

APPENDIX A

SCORING MODEL FOR USE IN EVALUATING DWMS DECISION PACKAGES

A description of the scoring model suggested for use by the DWMS Mission Area Review panel follows. The individual score for program i decision package j from panel member z is given by:

$$[\text{Individual Score}]_{ijz} = \Big[[\text{Military Value Score}]_{ij} + [\text{Feasibility Score}]_{ij} + [\text{Resource Acceptability Score}]_{ij}\Big] \qquad (1)$$

The total score or objective function coefficient for program i decision package j is determined by:

$$b_{ij} = [\text{Total Score}]_{ij} = [\text{Group Importance Score}]_{ij} \times \sum_{z=1}^{f} [\text{Individual Score}]_{ijz} \qquad \begin{array}{l} i = 1,2, \ldots, n \\ j = 1,2, \ldots, m_i \end{array}$$

where f is the total number of members on the DWMS Mission Area Review panel, n is the number of projects, and m_i is the number of decision packages for project i.

A checklist is now presented which will aid the DWMS panel members in evaluating each decision package against the provided criteria. For each evaluation criteria, a list of typical questions that should be considered is provided. After reviewing the provided list and any other questions that the DWMS panel deems relevant, each decision package is evaluated, and a number representing the value of that decision package to the AF selected from the provided scale. Once each decision package has been evaluated against the criteria, a decision package individual score is obtained by using formula 1.

Scoring Model Checklist

I. Military Value
(Relevance)

1	2	3	4
Low (No)			High (Yes)

A. Mission Accomplishment

1. If the program is technically successful, will the resulting system satisfy the need?

2. What is the final performance of the system being proposed by this DP?

3. Will the proposed system be effective?

B. Survivability

1. Will this DP result in a system that is survivable in the expected threat environment?

C. Long-Range Goals

1. Is this DP compatible with current AF strategy?

2. Are the objectives of this DP related to AF objectives?

D. System Improvement

1. Does this DP contribute to the improvement of a current or future system?

E. Timing

1. How soon is this system needed?

2. What is the expected development time?

3. What is the probability of obsolescence? Will the system be obsolete before it is developed? Will the threat change significantly so that this program is not needed?

II. Feasibility

1 2 3 4
Low High

A. Once this program is started, will it be successfully completed?

B. How realistic is this DP in the current political, economic, and technical environment?

1. Technical Feasibility

a. What is the technical risk of this DP?

b. Is the required technology available or does the DP depend upon a laboratory research program? Will the technology from the laboratory be available when required?

c. Have alternative technical solutions been explored for the relevant technological bottlenecks?

d. Are the required components available but have not been integrated to determine how they perform together?

e. Does this program rely on "off-the-shelf" components?

2. Political Feasibility

a. Who is the program's champion?

b. Does this DP, if selected by this panel, have a high probability of being funded?

3. Organizational Feasibility

a. Is the organization capable of performing the work?

b. Are the required engineers, scientists, material, facilities, and management available?

c. How well thought out is the program? Does the program sound realistic?

III. Resource Acceptability

1 2 3 4

Low High

A. General

1. Given that this program is desired, is the organization capable of performing the work?

2. Does this DP require a large percentage of the available resources?

3. Is this program efficient? Is this particular DP the most efficient method to achieve the program's objectives? Is the job being done for the least cost?

4. Are the future costs realistic?

B. Timing

1. Will resources be available when required?

2. Are the development costs versus time realistic?

IV. Importance

1 2 3 4

Low High

A. How important is this DP to AF strategy?

B. How important is this DP with respect to all other decision packages in the DWMS mission area?

C. How does this DP relate to the following priority structure?

1. Priority 1 - DP is directed toward, or is part of, a broader effort aimed at meeting a must requirement to achieve an AF objective or goal.

2. Priority 2 - DP is aimed at a less favored approach among several to meeting a must requirement.

3. Priority 3 - Project only contributes to a desired but not required goal.

Compulsory Projects

Next, the DWMS panel must flag compulsory projects. Compulsory projects will be formulated as constraints.

1. Is at least a certain DP required by law or regulation?

2. Has the AF committed itself to provide a certain level of funds to a joint program?

3. Does it make sense to fund an overhead program element at some other minimum level than DP 1?

Interdependencies

The following checklist will aid in determining the benefit adjustments required by considering interdependent programs.

1. Does this DP contribute to the standardization with other programs?

2. What are the effects on other R&D programs?

3. Is there an overlap in resource utilization between programs? Can two programs share manpower, facilities, or funds? Can two programs be completed together for less cost than each individually?

4. Can the technological breakthroughs on one program affect the outcome of another program?

5. Does selecting two programs have a synergistic or cannibalistic effect upon each other? What is the magnitude of that effect?

APPENDIX B

COMPUTER PROGRAM
FOR EXAMPLE 3

```
 TITLE
EXAMPLE OF 0-1 IP APPLIED TO THE POM R&D PROGRAM SELECTION PROBLEM
DSZ1IP
*
*    OBJECTIVE FUNCTION - MAXIMIZE PROGRAM BENEFITS
*
MAXIMIZE
4X11+28X12+34X13+45X14+47X15 +30X21+39X24 +30X31+42X32+50X33+51X34
+12X41+22X42+29X43+30X44  +11X51+15X54  +19X61+25X62+23X63+30X64
+13X71+18X72+26X73+28X74  +16X81+24X82+29X83+30X84
+31X91+36X92+41X93+44X94  +27X101+40X102+47X103+49X104
*
*    CONSTRAINTS
CONSTRAINTS
*
*    MUTUALLY EXCLUSIVE PROGRAM VERSIONS
*    ONLY ONE DECISION PACKAGE FOR EACH PROGRAM ELEMENT CAN BE
*    INCLUDED IN THE FINAL PORTFOLIO
*
 1.  X11+X12+X13+X14+X15.LE.1
 2.  X21+X24.LE.1
 3.  X31+X32+X33+X34.LE.1
 4.  X41+X42+X43+X44.LE.1
 5.  X51+X54.LE.1
 6.  X61+X62+X63+X64.LE.1
 7.  X71+X72+X73+X74.LE.1
 8.  X81+X82+X83+X84.LE.1
 9.  X91+X92+X93+X94.LE.1
10.  X101+X102+X103+X104.LE.1
*
*    COMPULSORY PROGRAM ELEMENT WITH LOWER BOUND
*    DECISION PACKAGE
*
*    AT LEAST DECISION PACKAGE X33 HAS TO BE CHOSEN
*
11.  X33+X34=1
*
*    ALTERNATE COMPULSORY PROGRAMS WITH LOWER BOUND
*    DECISION PACKAGES
*
*    EITHER AT LEAST DECISION PACKAGE X62 OR AT LEAST
*    DECISION PACKAGE X42 HAS TO BE CHOSEN
*
12.  X62+X63+X64+X42+X43+X44.GE.1
*
```

```
  *     BUDGET CONSTRAINTS
*
*     BUDGET YEAR 1
*
13. 7X11+14X12+27X13+38X14+51X15  +16X21+31X24
    +13X31+26X32+52X33+61X34  +6X41+11X42+22X43+34X44
    +102X51+124X54  +11X61+21X62+42X63+51X64
    +9X71+19X72+37X73+48X74  +5X81+11X82+22X83+39X84
    +13X91+21X92+36X93+49X94  +64X101+79X102+88X103+101X104
    .LE.350
*
*     BUDGET YEAR 2
*
14. 8X11+15X12+28X13+39X14+42X15  +36X21+40X24
    +14X31+29X32+57X33+67X34  +7X41+12X42+24X43+36X44
    +108X51+129X54  +12X61+23X62+45X63+54X64
    +10X71+21X72+41X73+53X74  +7X81+12X82+23X83+39X84
    +10X91+18X92+34X93+42X94  +67X101+82X102+91X103+102X104
    .LE.343
*
*     BUDGET YEAR 3
*
15. 9X11+16X12+30X13+40X14+43X15  +42X21+43X24
    +16X31+31X32+63X33+74X34  +8X41+13X42+22X43+38X44
    +115X51+134X54  +13X61+24X62+49X63+57X64
    +11X71+23X72+43X73+56X74  +8X81+13X82+23X83+40X84
    +7X91+8X92+12X93+25X94  +71X101+85X102+93X103+103X104
    .LE.340
*
*     BUDGET YEAR 4
*
16. 11X11+18X12+32X13+42X14+43X15  +48X21+49X24
    +17X31+35X32+69X33+81X34  +10X41+15X42+29X43+40X44
    +121X51+139X54  +13X61+23X62+40X63+49X64
    +14X71+24X72+46X73+60X74  +9X81+15X82+24X83+40X84
                              +74X101+88X102+96X103+101X104
    .LE.336
*
*     BUDGET YEAR 5
*
17. 12X11+19X12+34X13+43X14+43X15  +50X21+52X24
    +19X31+38X32+76X33+89X34  +11X41+17X42+32X43+41X44
    +129X51+142X54  +8X61+18X62+26X63+29X64
    +16X71+26X72+49X73+63X74  +12X81+17X82+25X83+41X84
                              +78X101+89X102+99X103+100X104
    .LE.341
    PRINT
    LIMIT 500000
    OPTIMIZE
```

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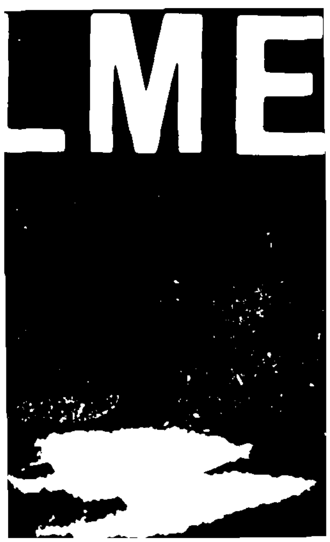
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